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Wenger et al.

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(45) **Date of Patent: Jul. 30, 2013**

(54) **ELECTRIC VEHICLE AND ON-BOARD BATTERY CHARGING APPARATUS THEREFORE**

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(73) Assignee: **Swissauto Powersport LLC**, Burgdorf (CH)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/737,149**

(22) PCT Filed: **Sep. 16, 2010**

(86) PCT No.: **PCT/US2010/049167**

§ 371 (c)(1),
(2), (4) Date: **Dec. 13, 2010**

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PCT Pub. Date: **Mar. 24, 2011**

(65) **Prior Publication Data**

US 2011/0298219 A1 Dec. 8, 2011

Related U.S. Application Data

(60) Provisional application No. 61/358,308, filed on Jun. 24, 2010.

(30) **Foreign Application Priority Data**

Sep. 16, 2009 (EP) 09170400

(51) **Int. Cl.**
B60K 6/42 (2007.10)

(52) **U.S. Cl.**
USPC **180/65.22**

(58) **Field of Classification Search**
USPC 180/65.1–65.29
See application file for complete search history.

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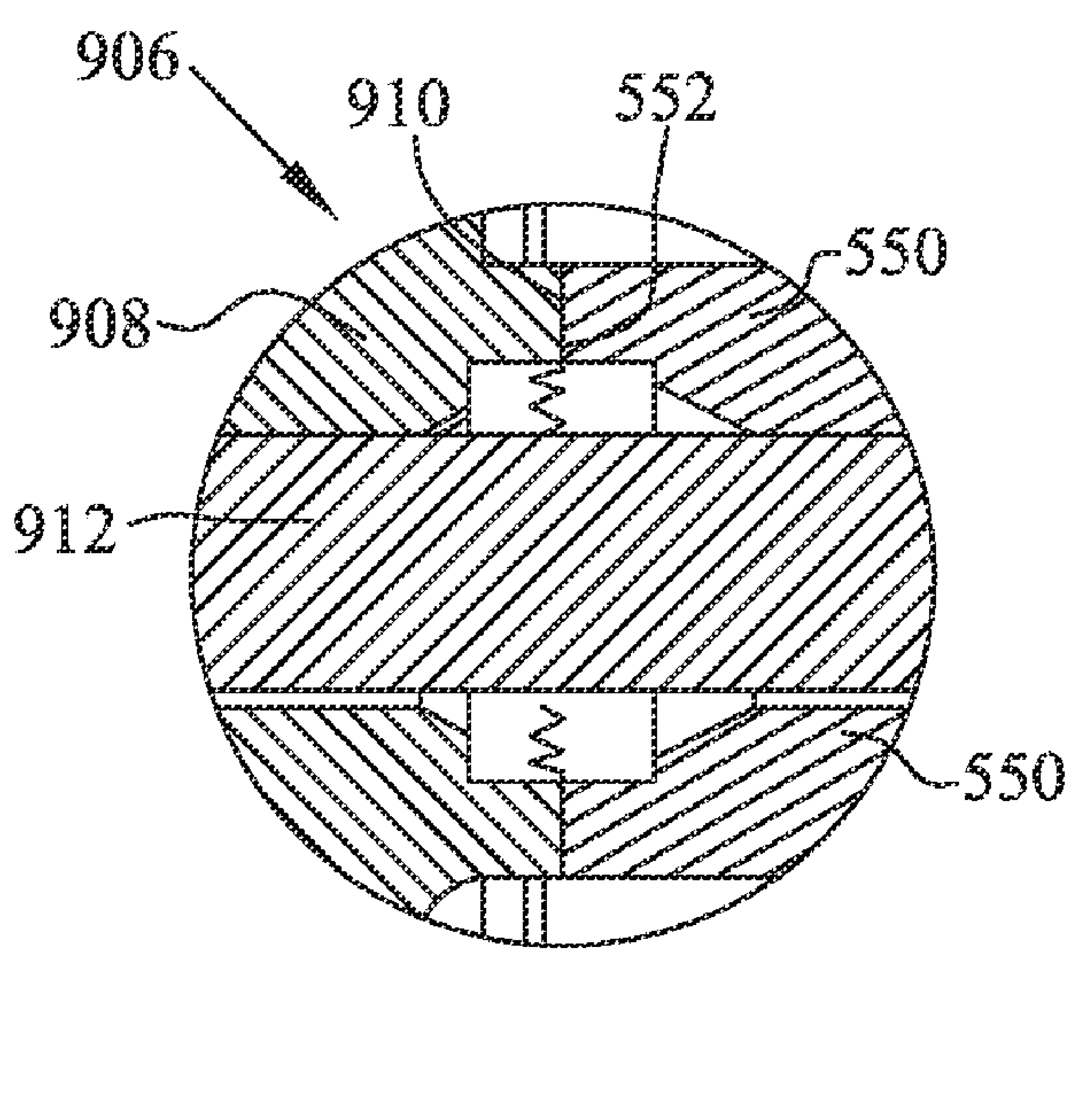
Primary Examiner — J. Allen Shriver, II
Assistant Examiner — Erez Gurari
(74) *Attorney, Agent, or Firm* — Faegre Baker Daniels LLP

(57) **ABSTRACT**

An electric vehicle and a range extender engine are shown including the controls to operate the same.

7 Claims, 37 Drawing Sheets



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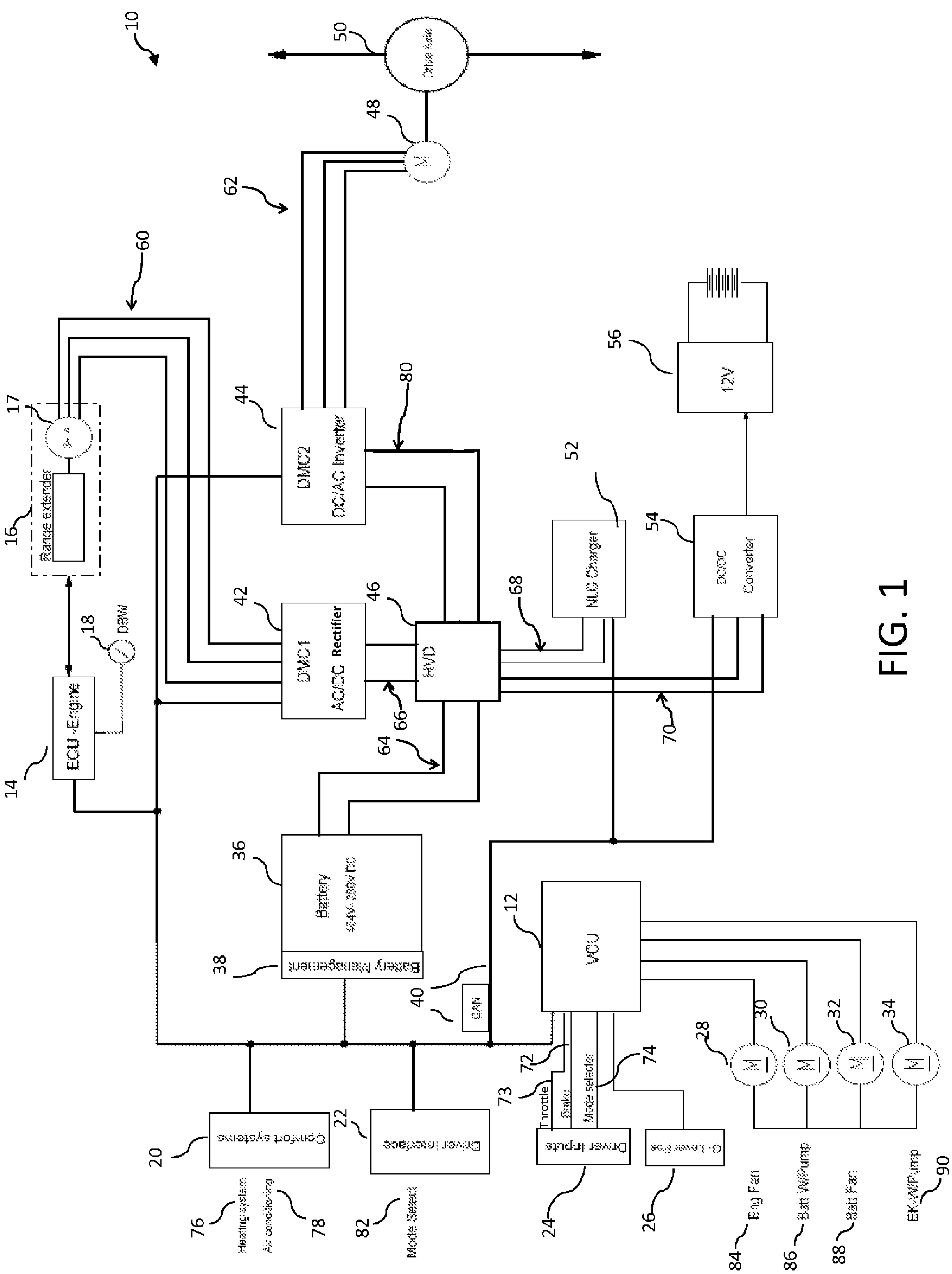
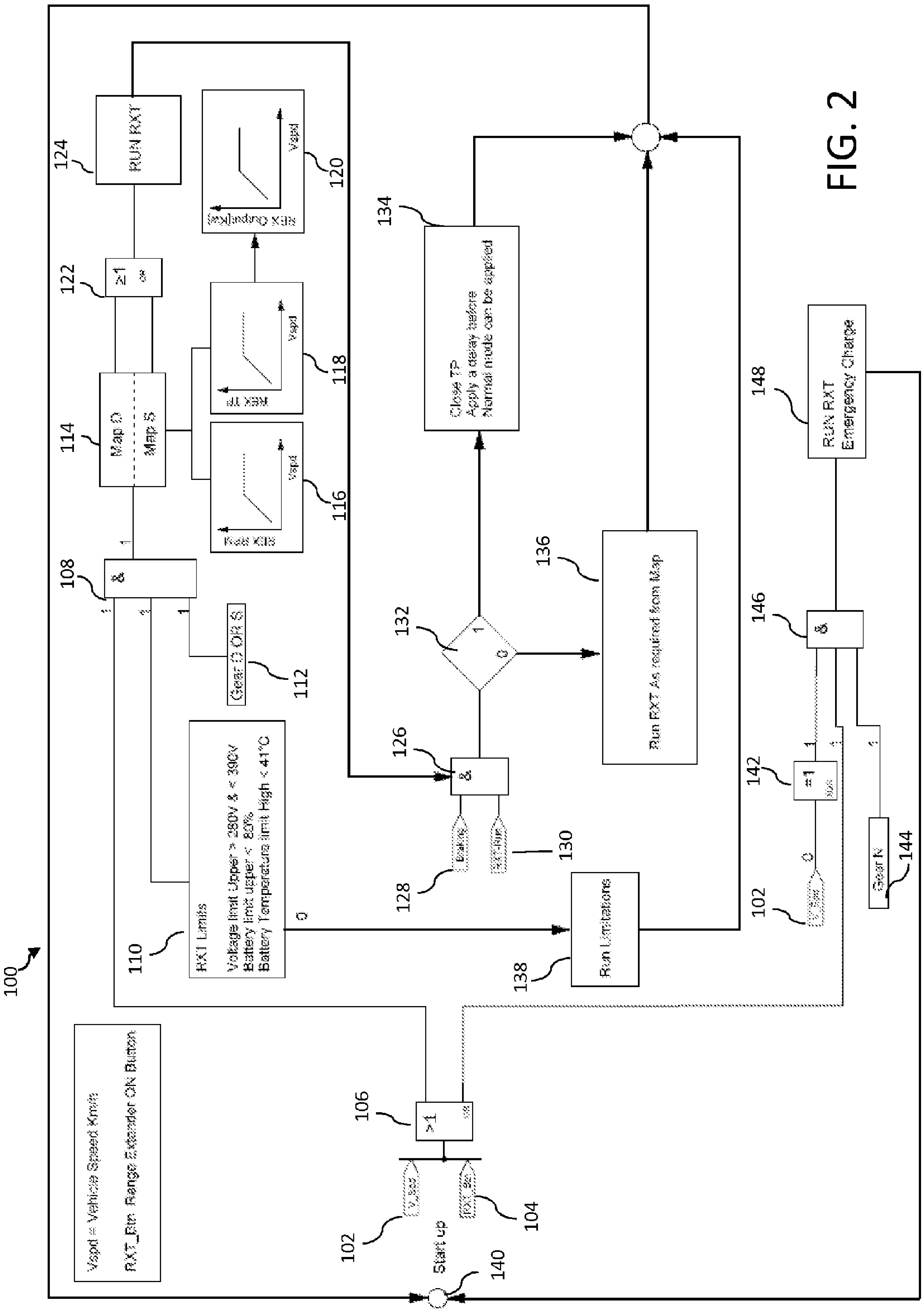

10
50
48
62
60
17
16
Range extender
14
ECU - Engine
18
DBW
44
DMC2
DC/AC Inverter
80
42
DMC1
AC/DC Rectifier
46
HVD
66
64
68
52
NLG Charger
54
DC/DC
Converter
56
12V
70
36
Battery
38
Battery Management
40
CAN
12
VCU
72
73
74
Throttle
Brake
Mode selector
28
30
32
34
20
Comfort systems
22
Driver interface
24
Driver inputs
26
76
Heating system
Air conditioning
78
82
Mode Select
84
Eng Fan
86
Batt W/Pump
88
Batt Fan
EK W/Pump
90

FIG. 1



100
124
RUN RXT
122
≥1
114
Map D
Map S
116
118
120
Vspd
108
&
112
Gear D OR S
110
RXT Limits
Voltage limit Upper > 280V & < 390V
Battery limit upper < 80%
Battery Temperature limit High < 41°C
126
&
128
130
132
134
Close TP
Apply a delay before
Normal mode can be applied
136
Run RXT As required from Map
138
Run Limitations
142
144
Gear N
146
&
148
RUN RXT
Emergency Charge
102
104
106
>1
140
Start up
Vspd = Vehicle Speed Kmh
RXT_Btn Range Extender ON Button

FIG. 2

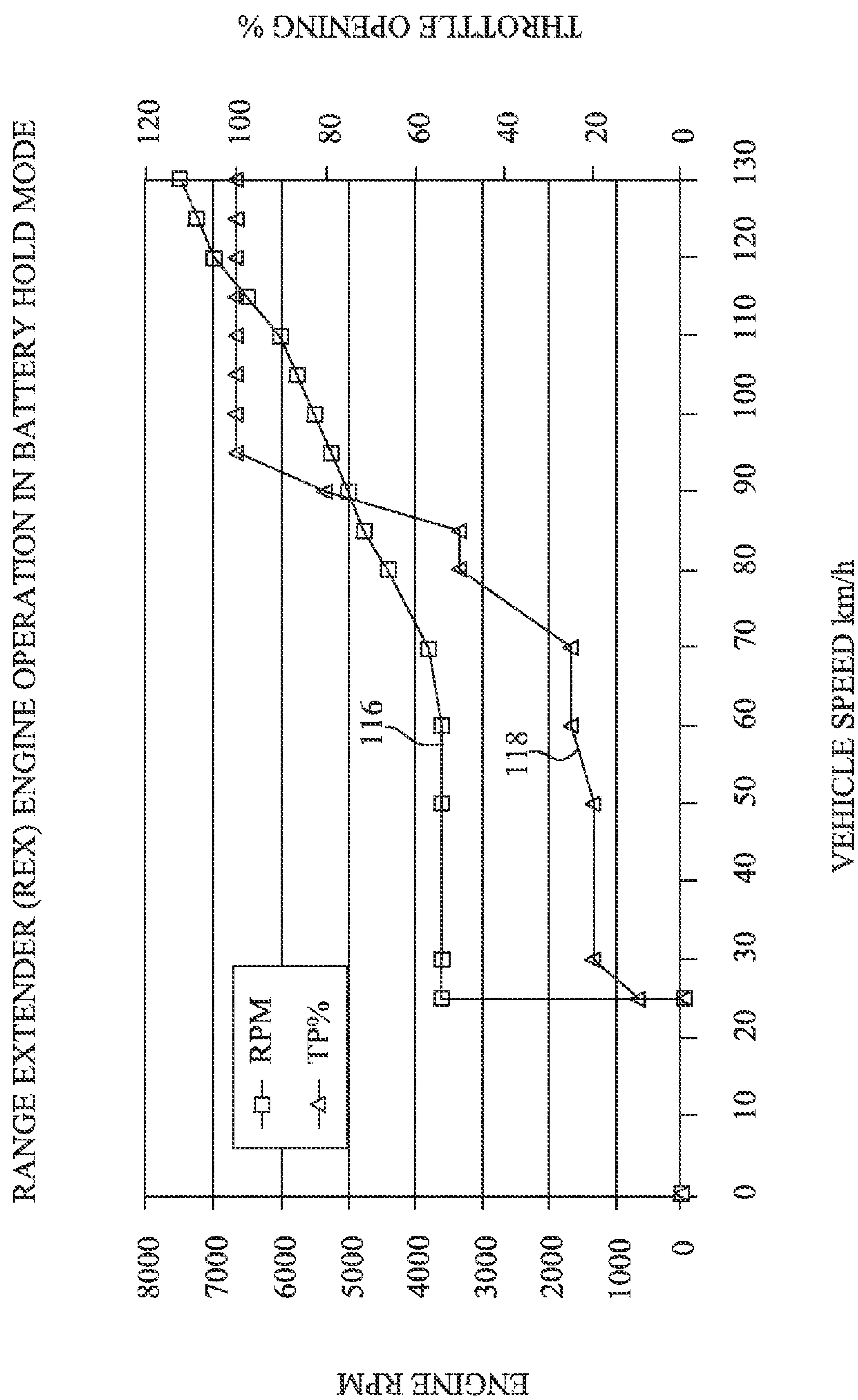

RANGE EXTENDER (REX) ENGINE OPERATION IN BATTERY HOLD MODE
ENGINE RPM
8000
7000
6000
5000
4000
3000
2000
1000
0
THROTTLE OPENING %
120
100
80
60
40
20
0
VEHICLE SPEED km/h
0
10
20
30
40
50
60
70
80
90
100
110
120
130
RPM
TP%
116
118

FIG. 3

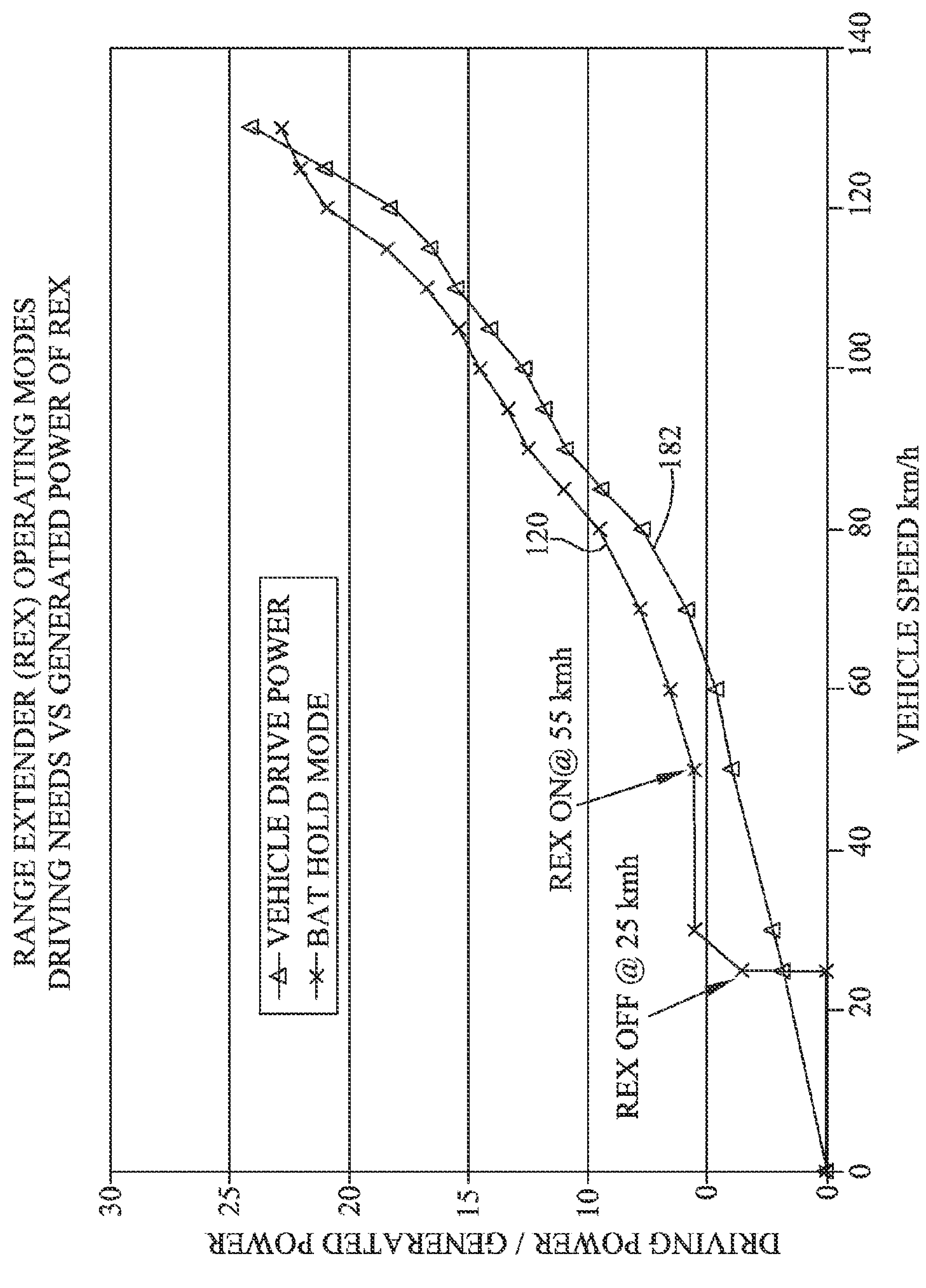

RANGE EXTENDER (REX) OPERATING MODES
DRIVING NEEDS VS GENERATED POWER OF REX
VEHICLE DRIVE POWER
BAT HOLD MODE
REX ON@ 55 kmh
REX OFF @ 25 kmh
120
182
DRIVING POWER / GENERATED POWER
VEHICLE SPEED km/h
0
5
10
15
20
25
30
0
20
40
60
80
100
120
140

FIG. 4

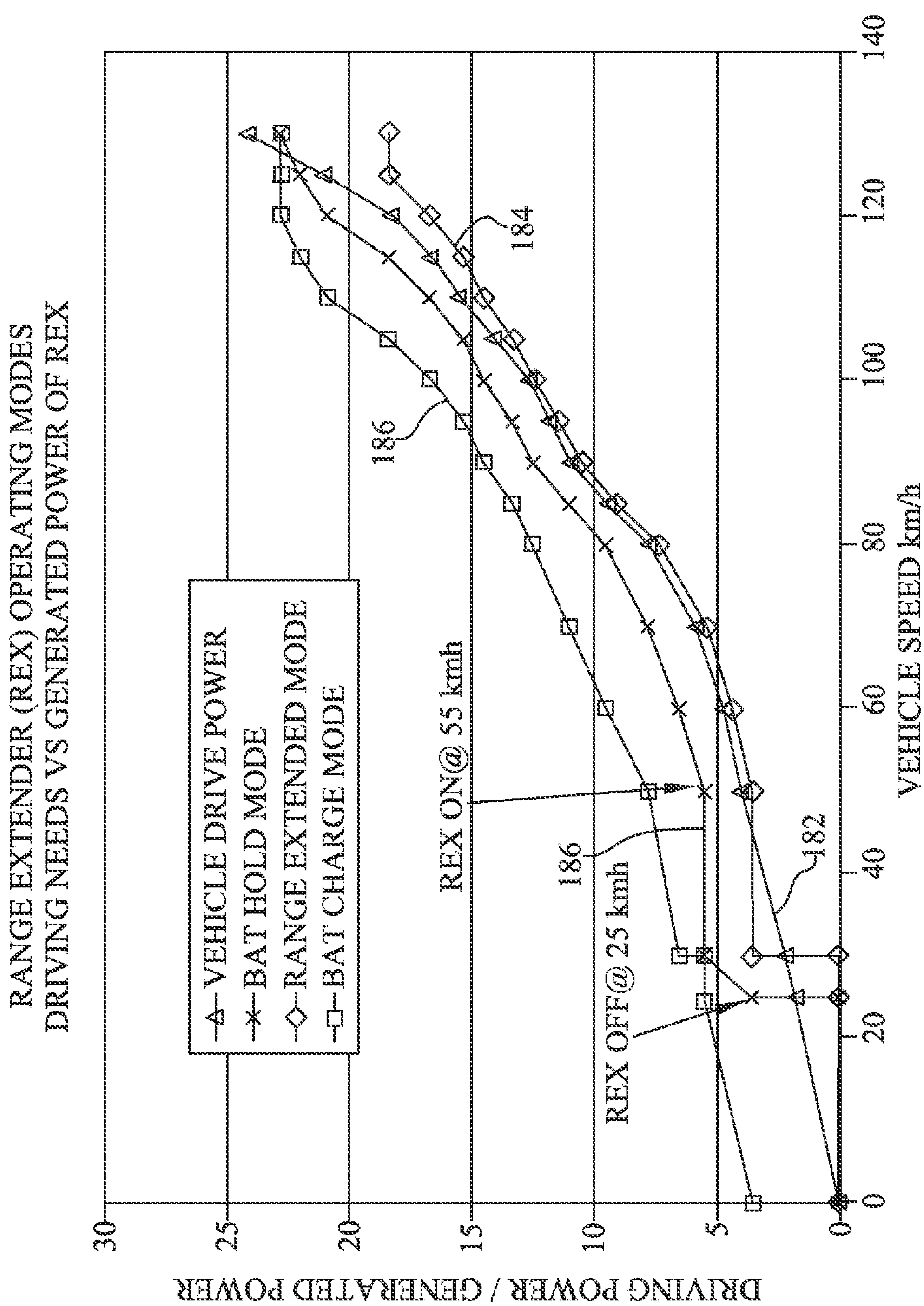

RANGE EXTENDER (REX) OPERATING MODES
DRIVING NEEDS VS GENERATED POWER OF REX
VEHICLE DRIVE POWER
BAT HOLD MODE
RANGE EXTENDED MODE
BAT CHARGE MODE
REX ON@ 55 kmh
REX OFF@ 25 kmh
186
186
184
182
DRIVING POWER / GENERATED POWER
VEHICLE SPEED km/h
0
5
10
15
20
25
30
0
20
40
60
80
100
120
140

FIG. 5

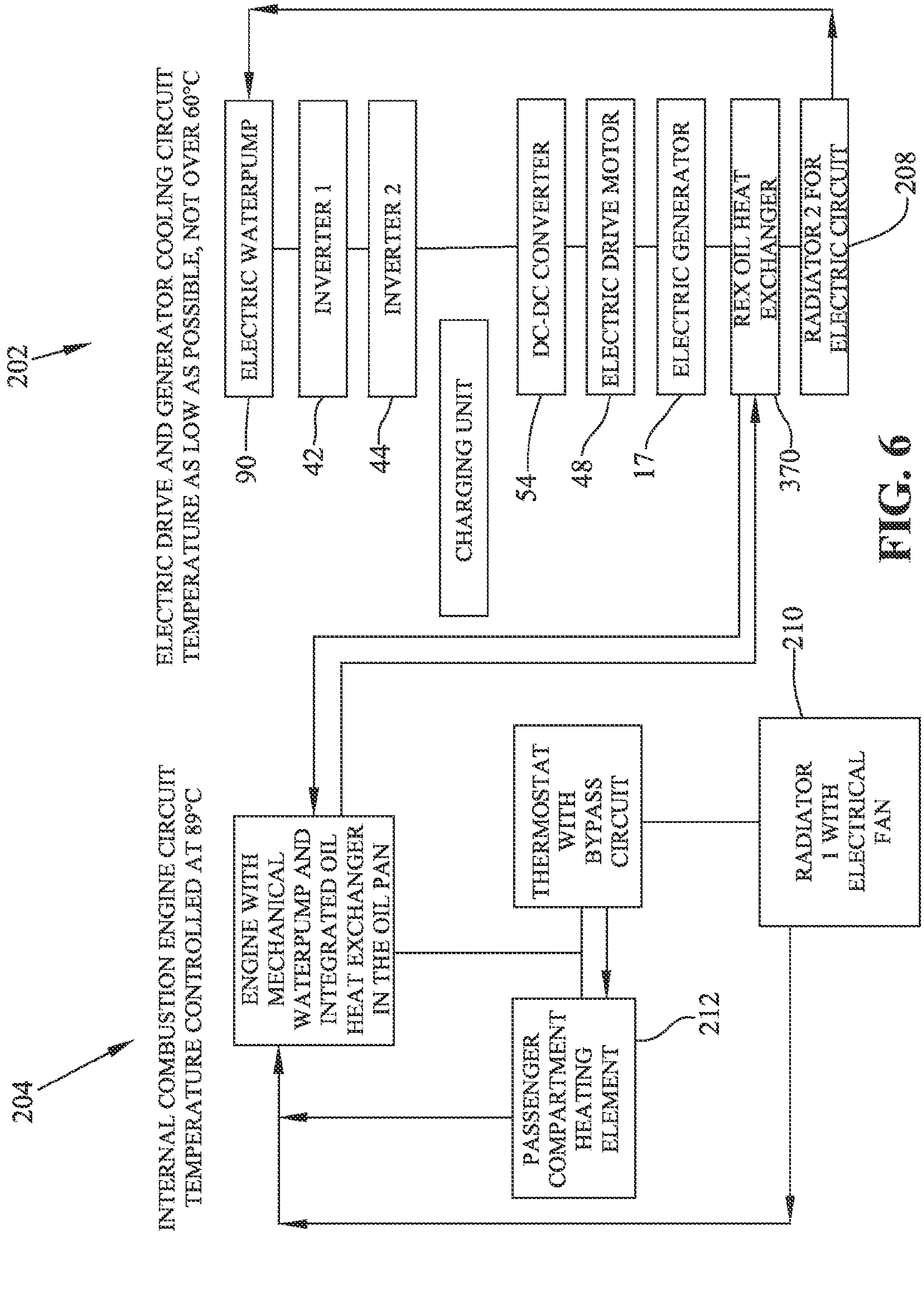

202
ELECTRIC DRIVE AND GENERATOR COOLING CIRCUIT
TEMPERATURE AS LOW AS POSSIBLE, NOT OVER 60°C
ELECTRIC WATERPUMP
90
INVERTER 1
42
INVERTER 2
44
CHARGING UNIT
DC-DC CONVERTER
54
ELECTRIC DRIVE MOTOR
48
ELECTRIC GENERATOR
17
REX OIL HEAT EXCHANGER
370
RADIATOR 2 FOR ELECTRIC CIRCUIT
208
204
INTERNAL COMBUSTION ENGINE CIRCUIT
TEMPERATURE CONTROLLED AT 89°C
ENGINE WITH MECHANICAL WATERPUMP AND INTEGRATED OIL HEAT EXCHANGER IN THE OIL PAN
THERMOSTAT WITH BYPASS CIRCUIT
RADIATOR 1 WITH ELECTRICAL FAN
210
PASSENGER COMPARTMENT HEATING ELEMENT
212

FIG. 6

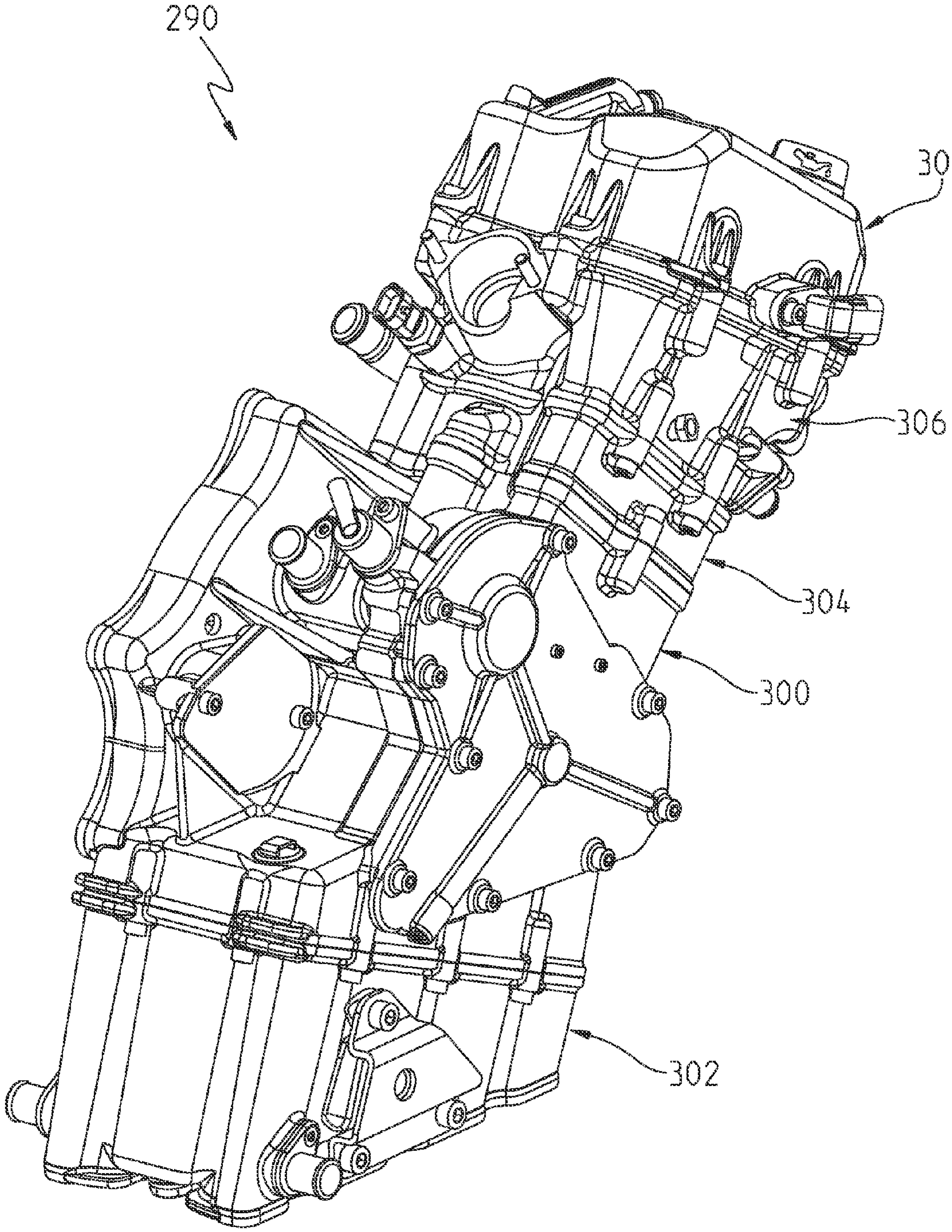


FIG. 7

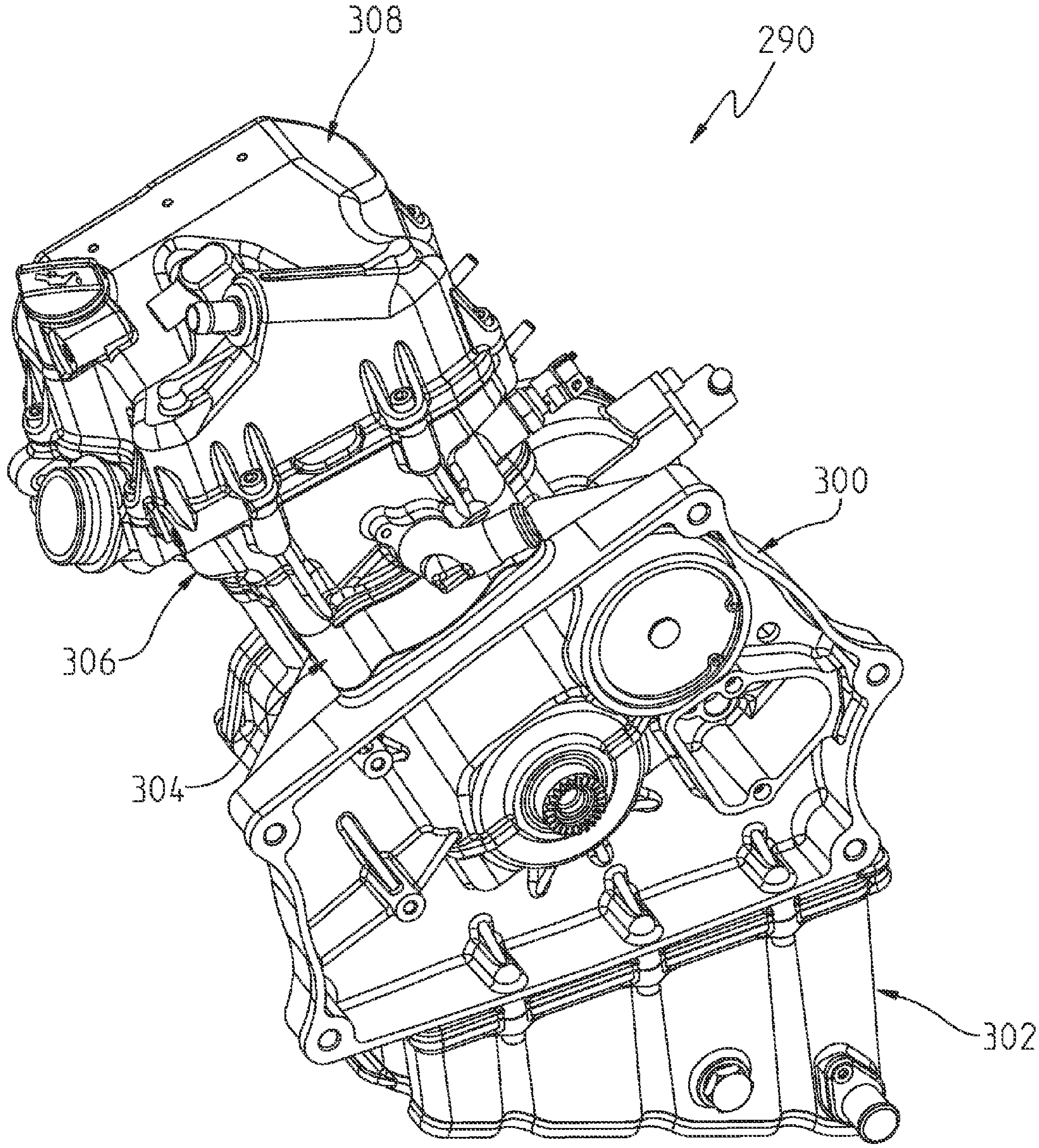


FIG. 8

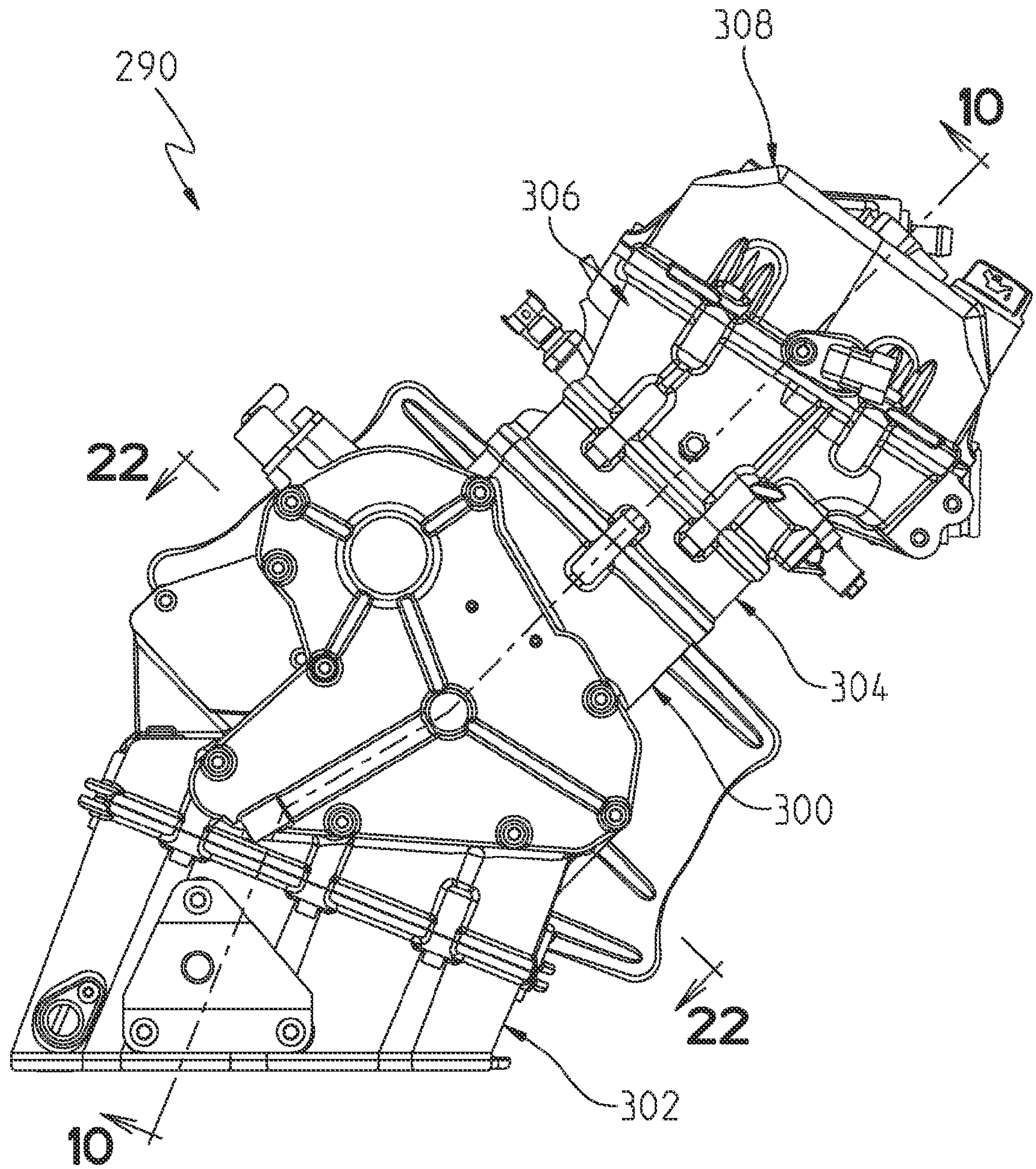
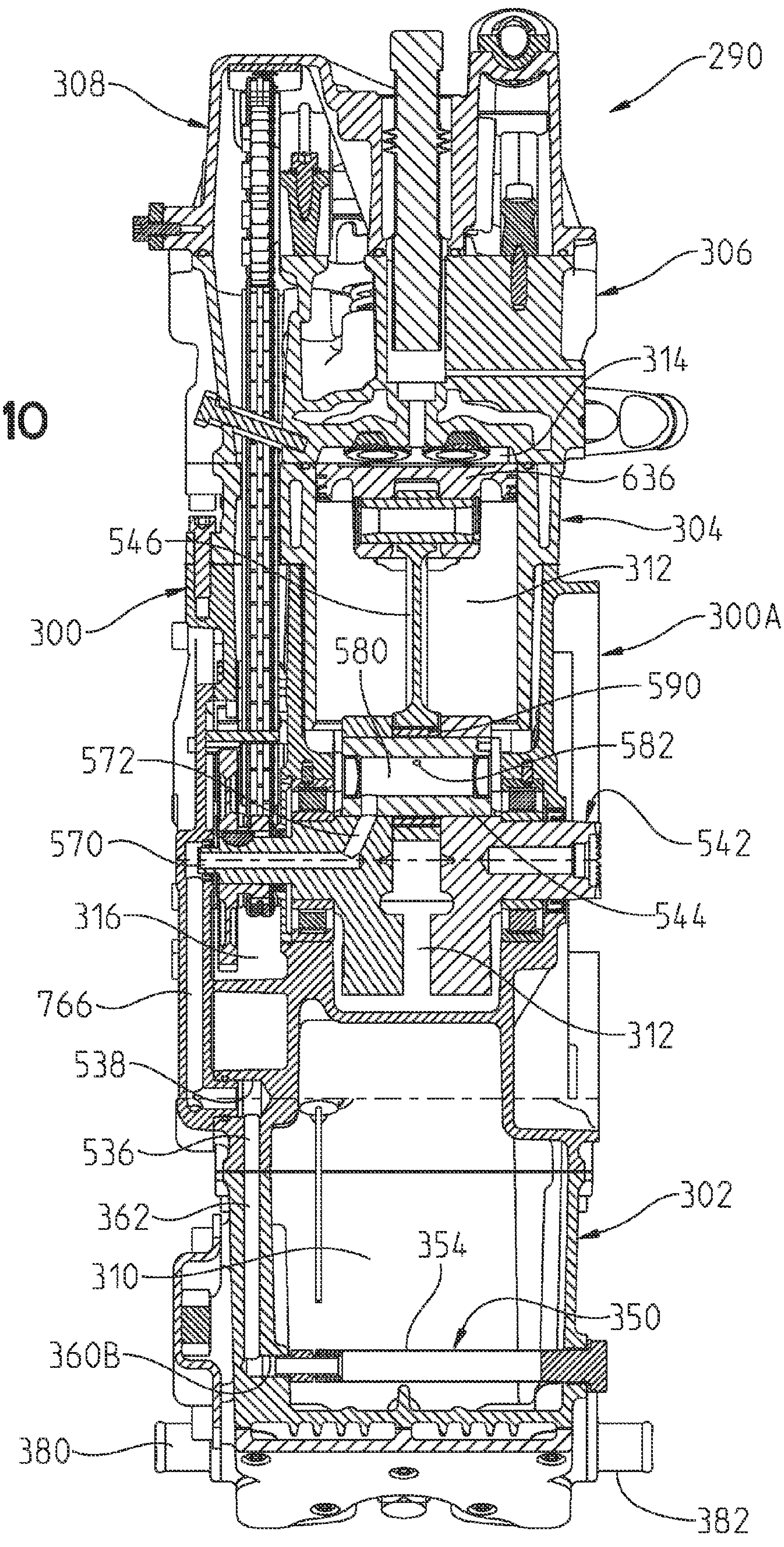


FIG. 9

FIG. 10


290
308
306
314
636
304
546
312
300
300A
580
590
572
582
542
570
544
316
766
312
538
536
302
362
354
310
350
360B
380
382

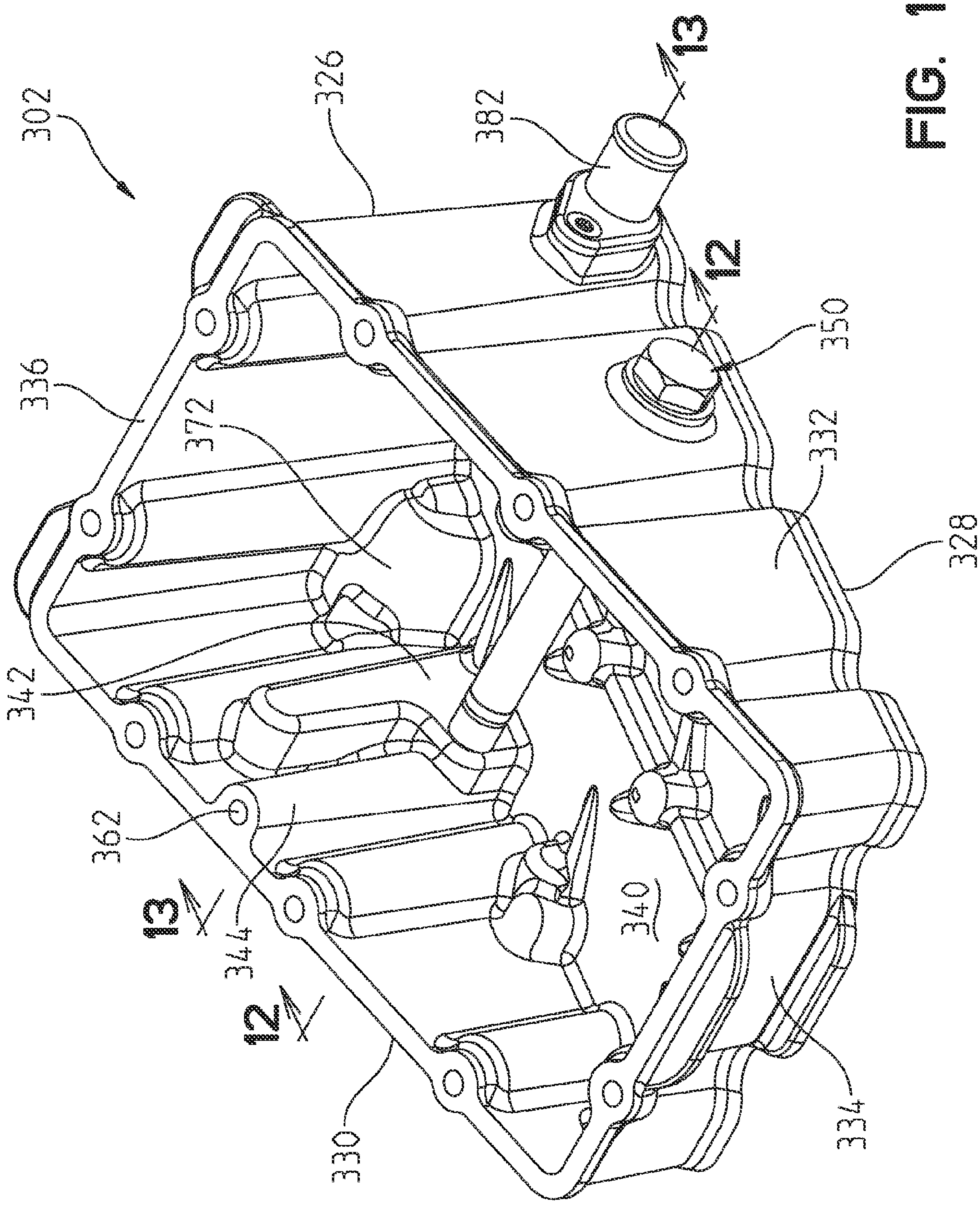

302
326
382
13
12
350
336
372
332
328
342
362
13
344
340
12
330
334

FIG. 11A

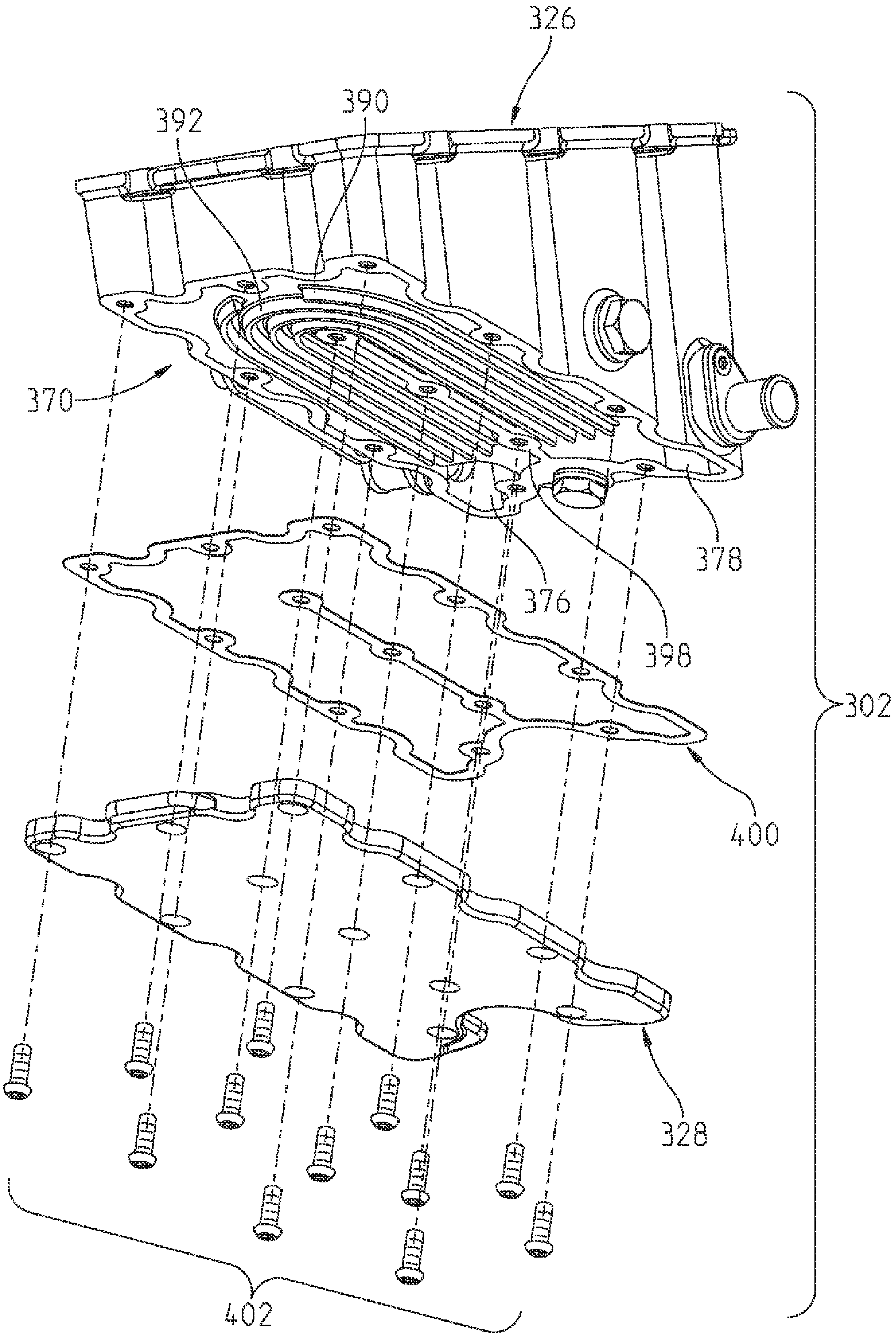


FIG. 11B

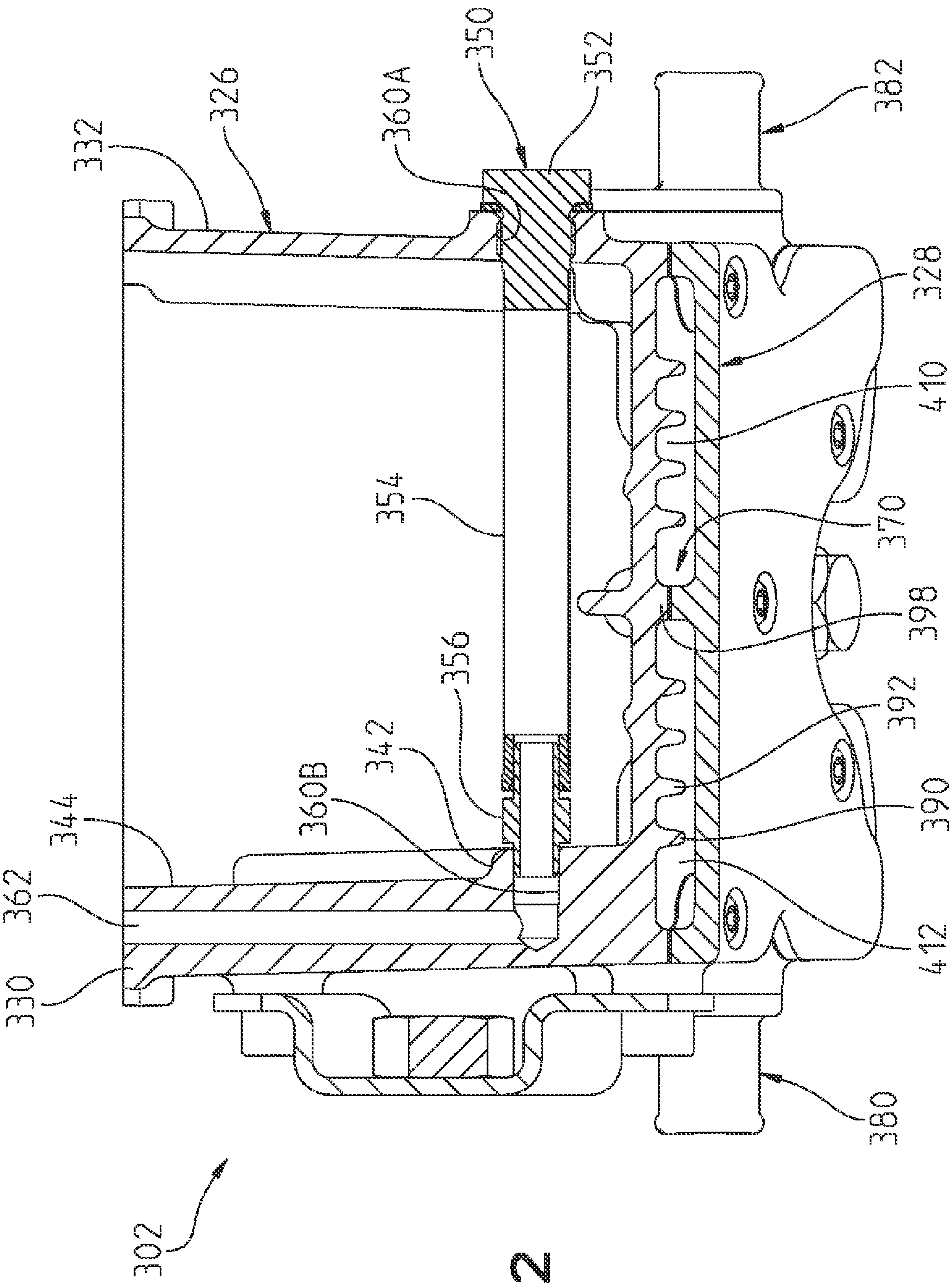

332
326
360A
350
352
382
328
410
354
370
398
356
392
342
360B
344
390
362
412
330
380
302

FIG. 12

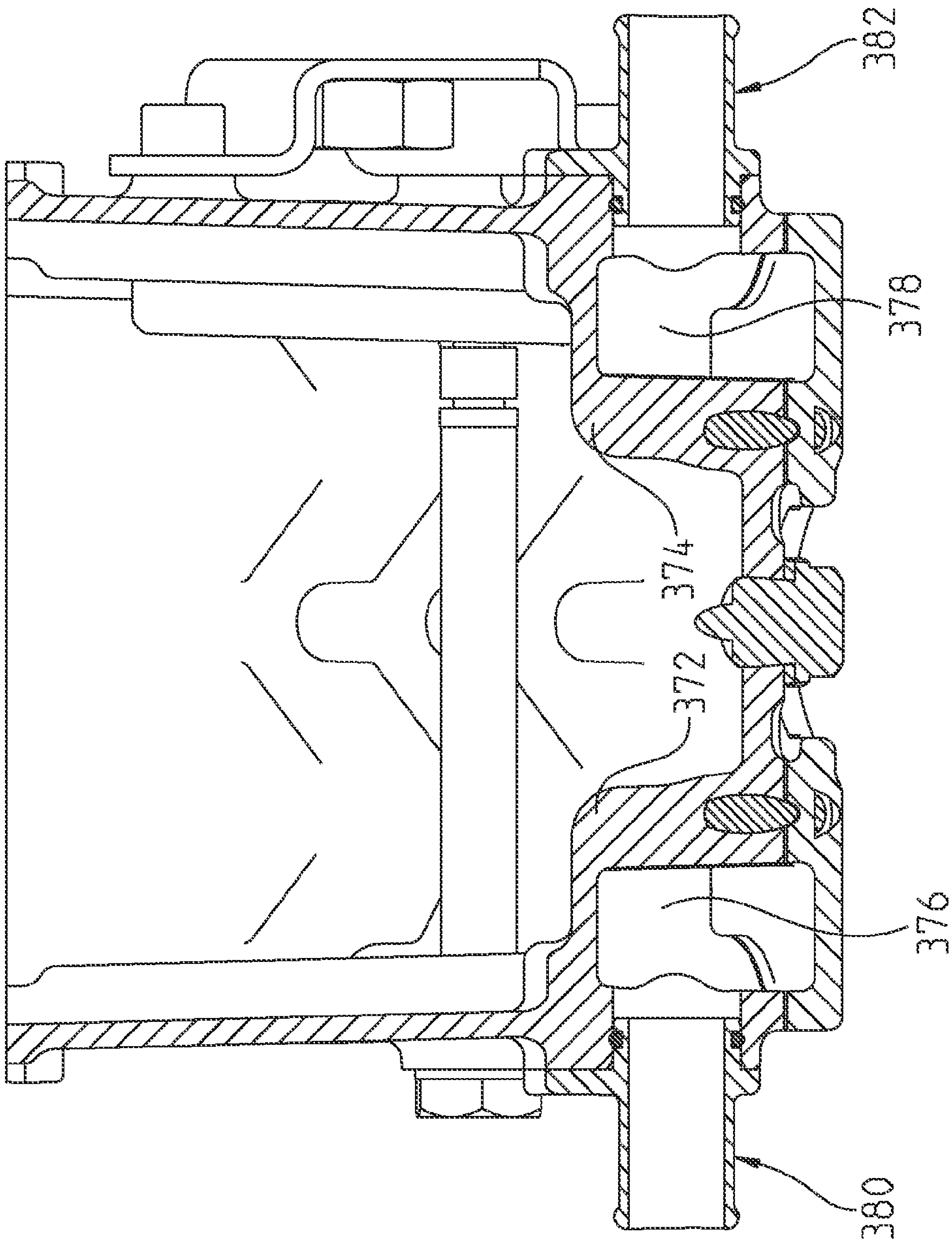


FIG. 13

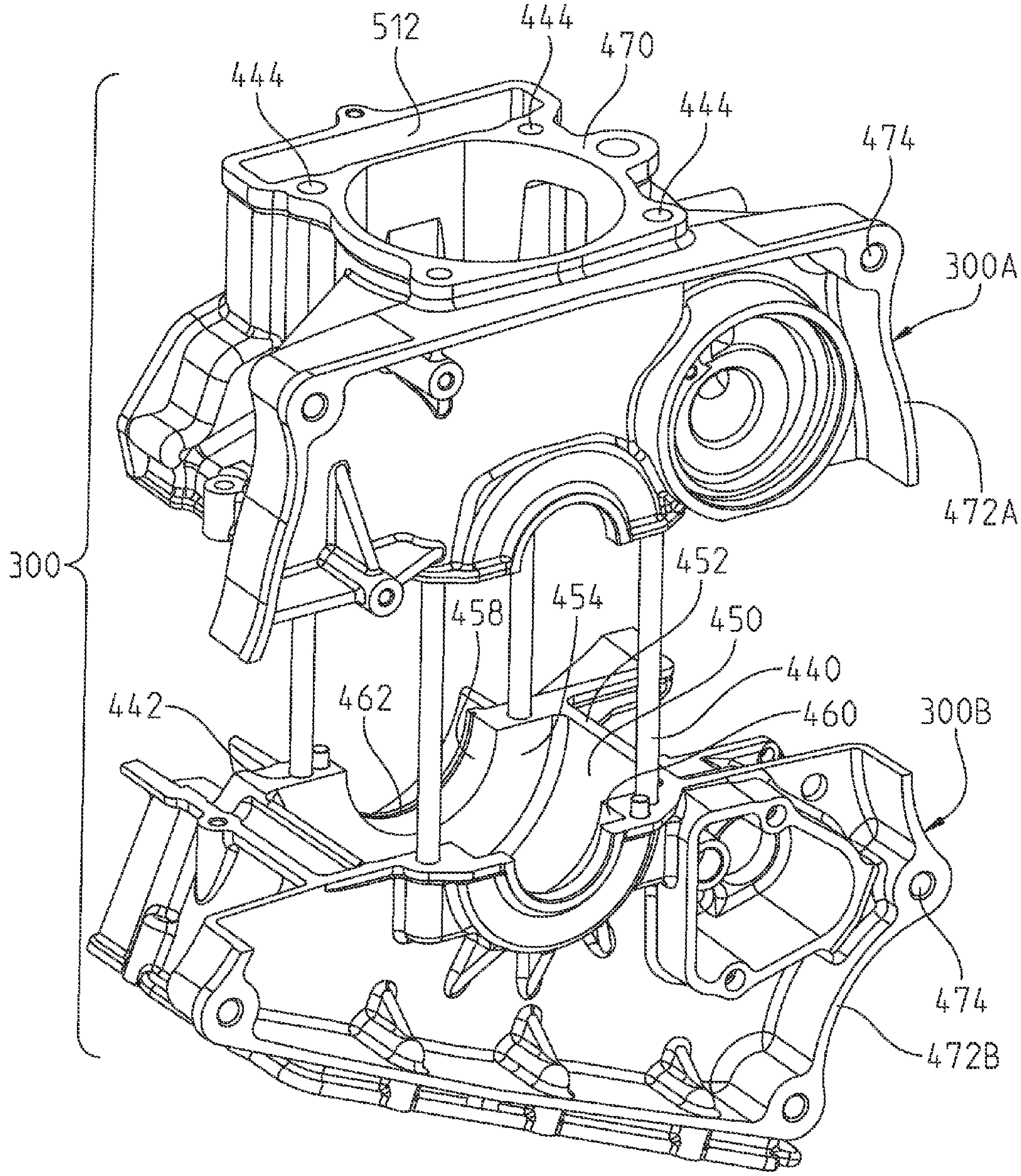

512
444
444
470
444
474
300A
472A
300
452
458
454
450
440
442
462
460
300B
474
472B

FIG. 14

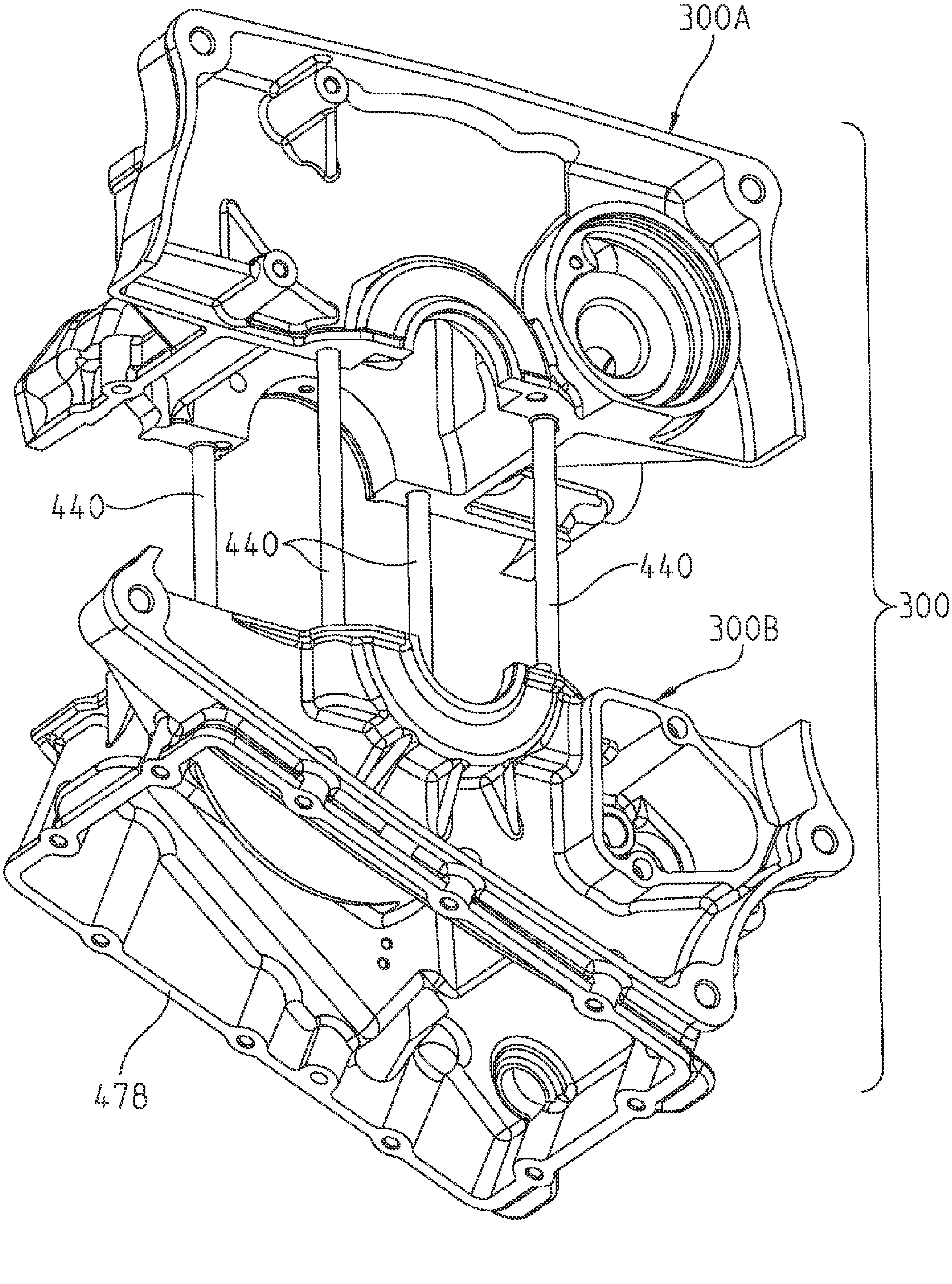


FIG. 15

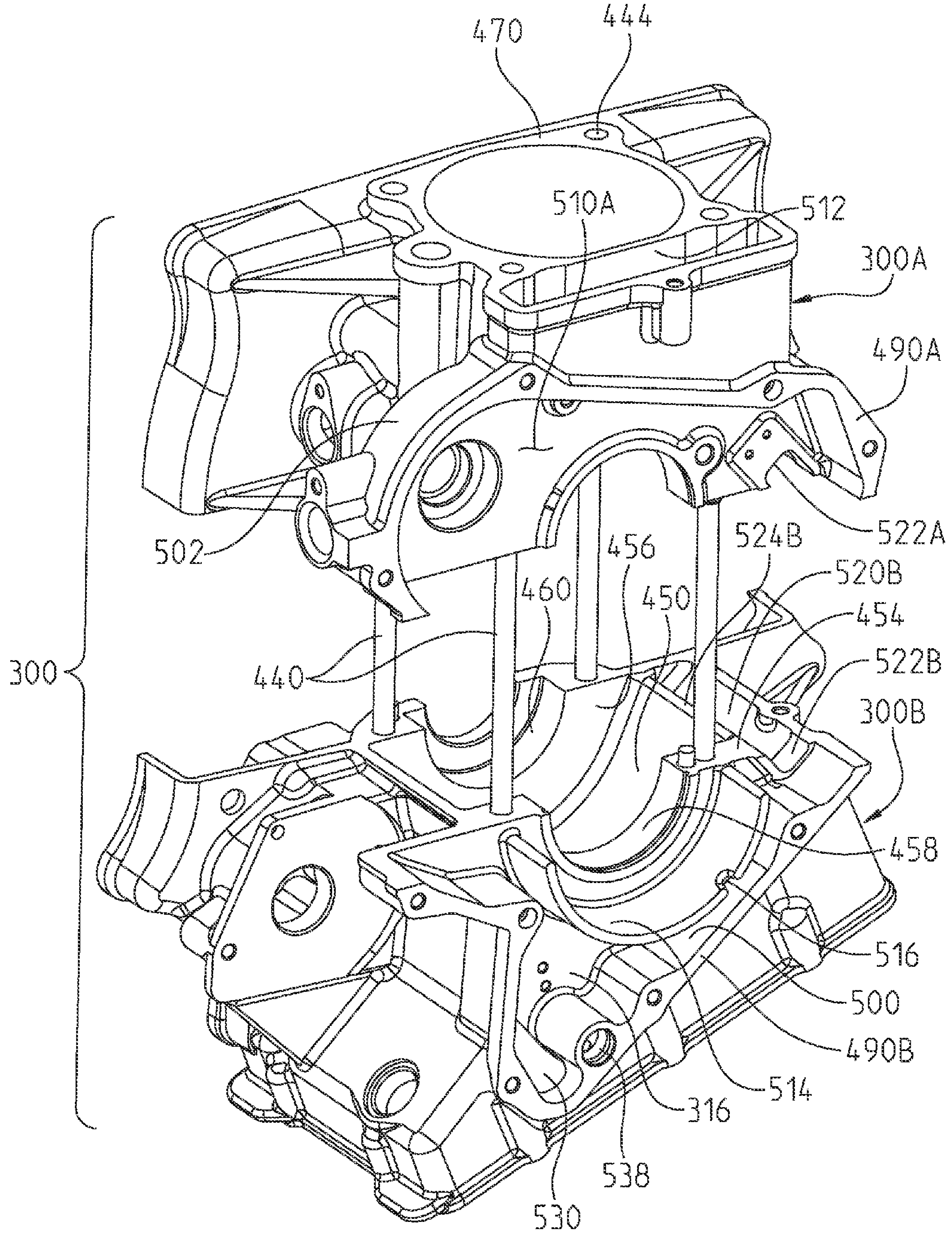

470
444
510A
512
300A
490A
522A
502
456
524B
520B
460
450
454
522B
440
300
300B
458
516
500
490B
514
316
538
530

FIG. 16

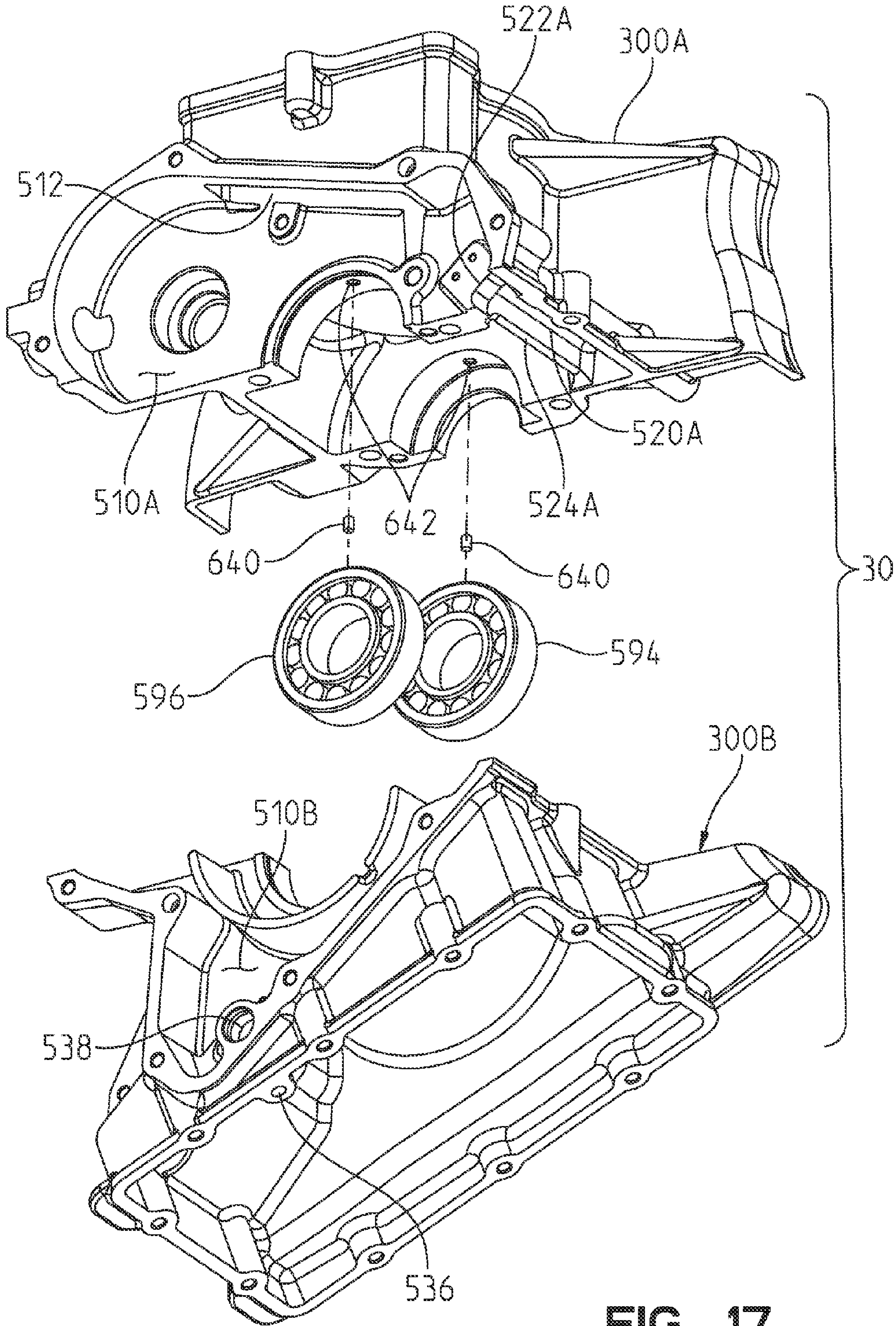

522A
300A
512
520A
510A
642
524A
640
640
300
596
594
300B
510B
538
536

FIG. 17

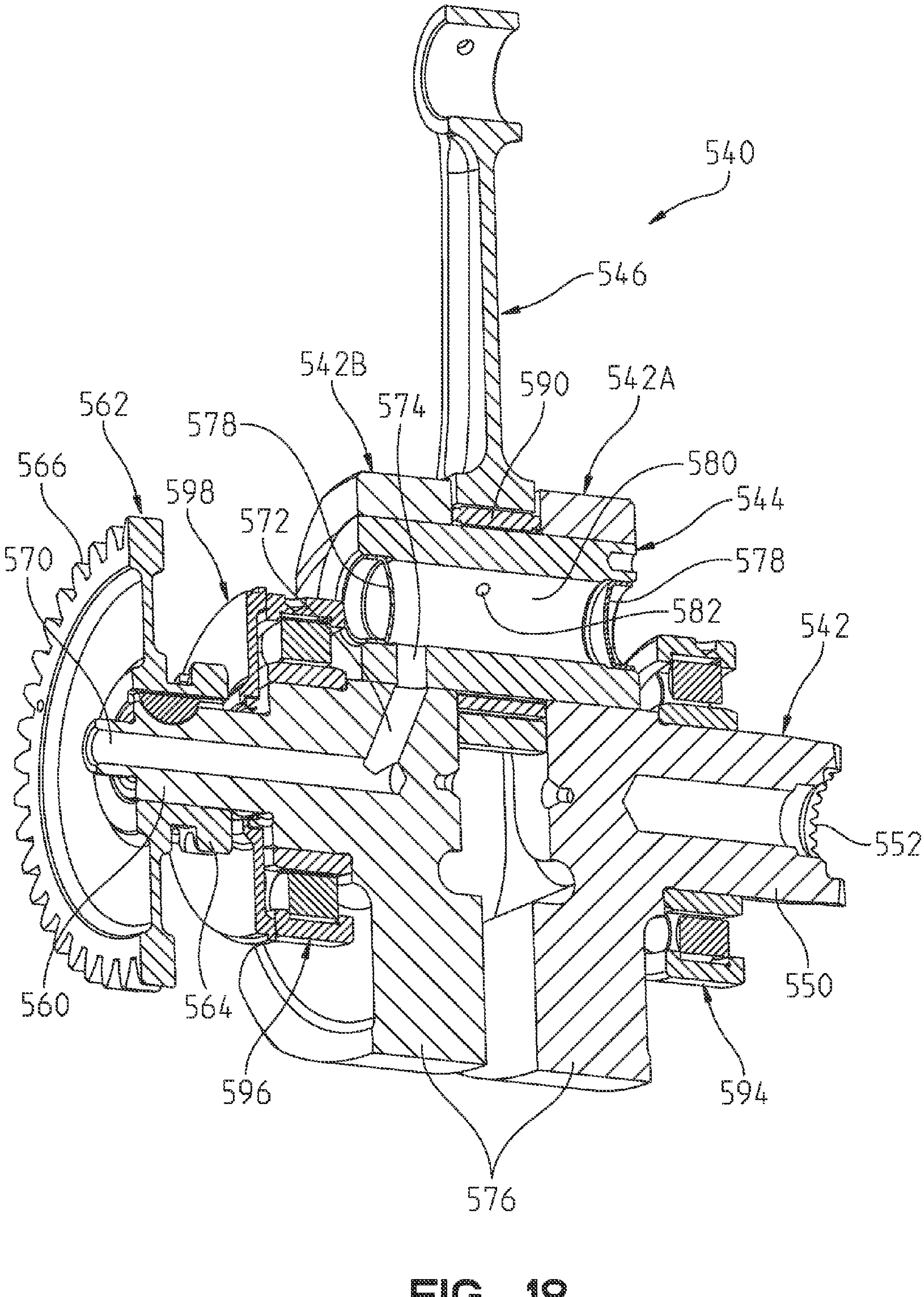

540
546
542B
574
590
542A
562
578
580
566
598
544
572
570
578
582
542
552
560
564
550
596
594
576

FIG. 18

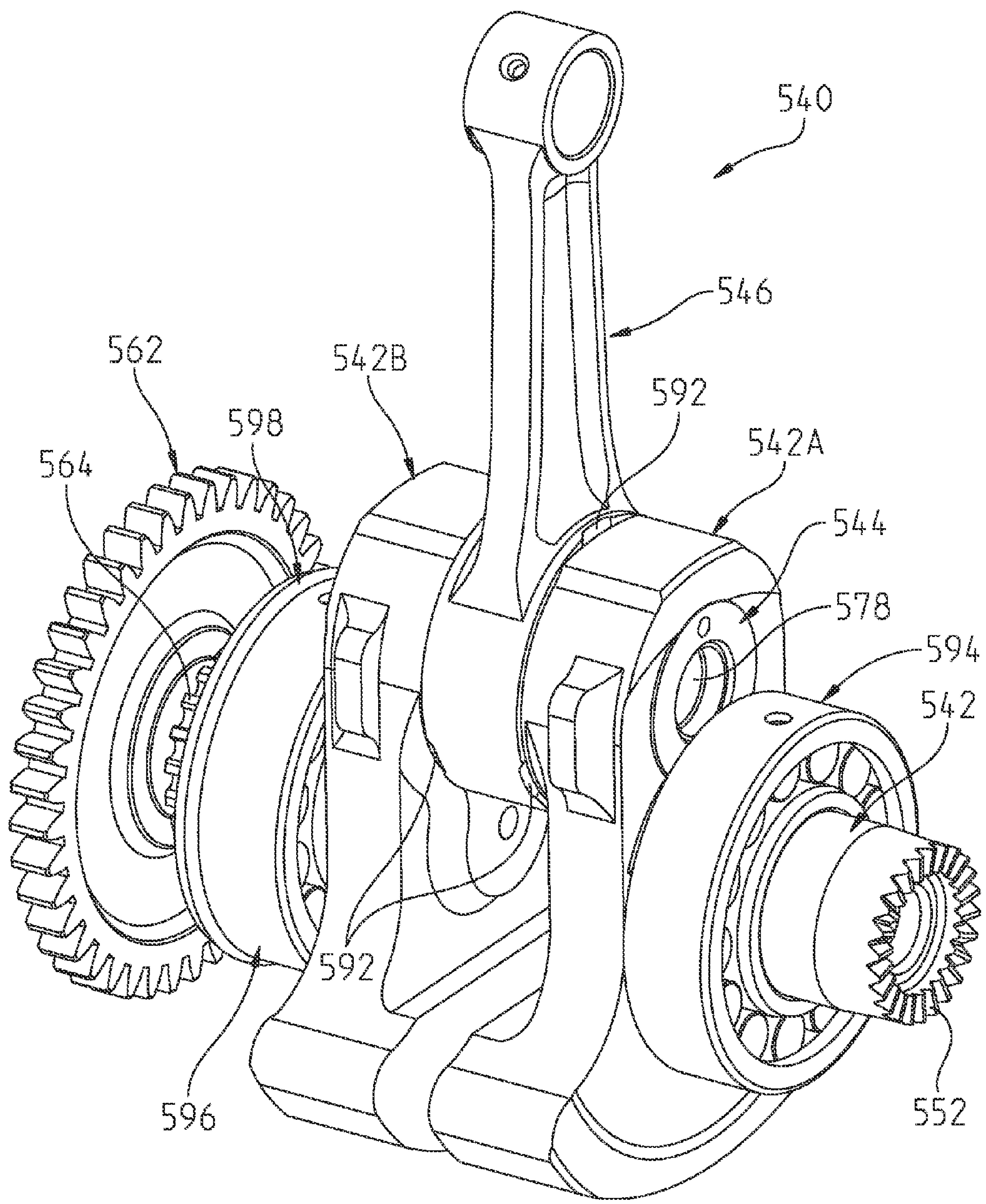


FIG. 19

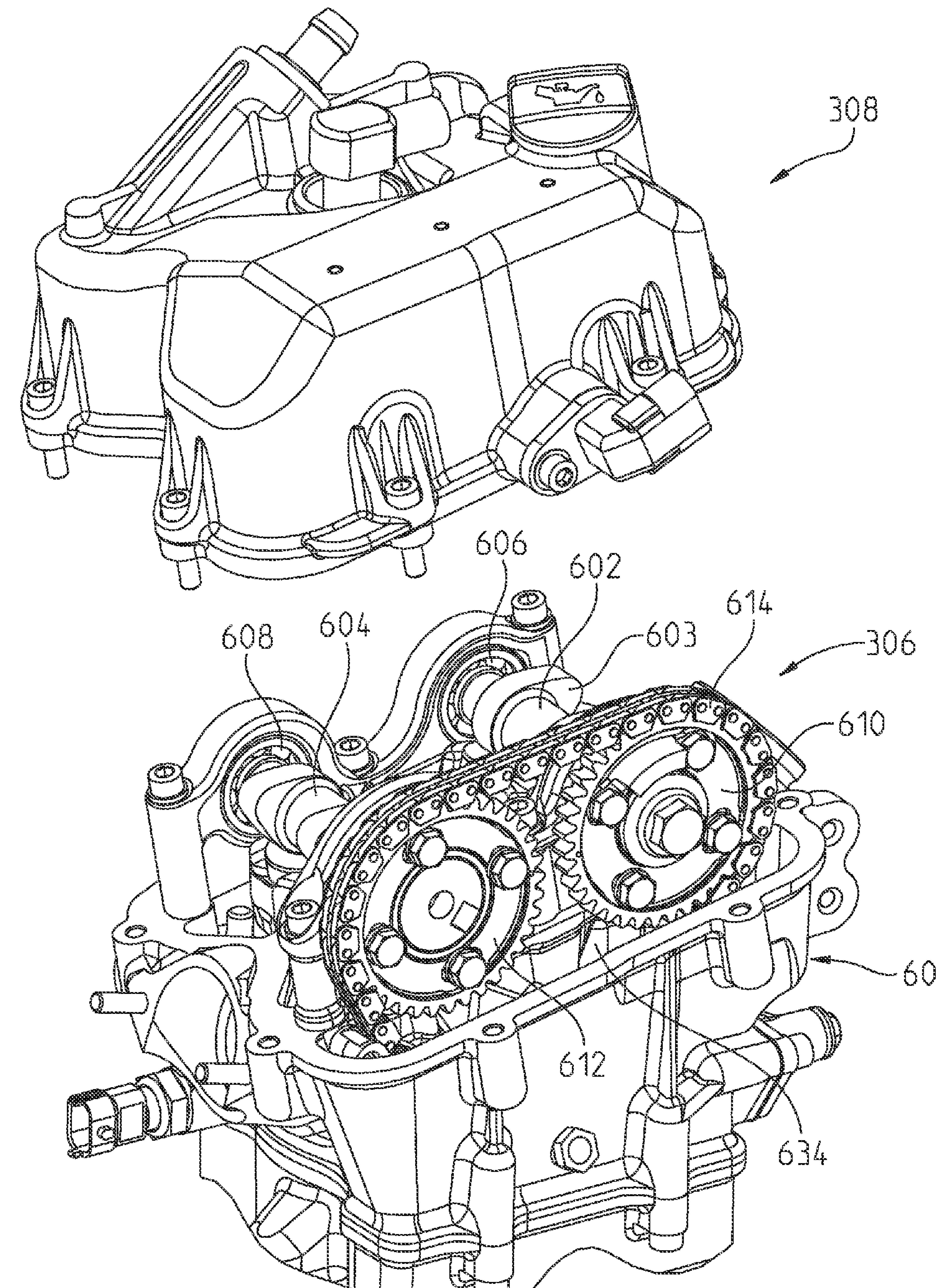


FIG. 20

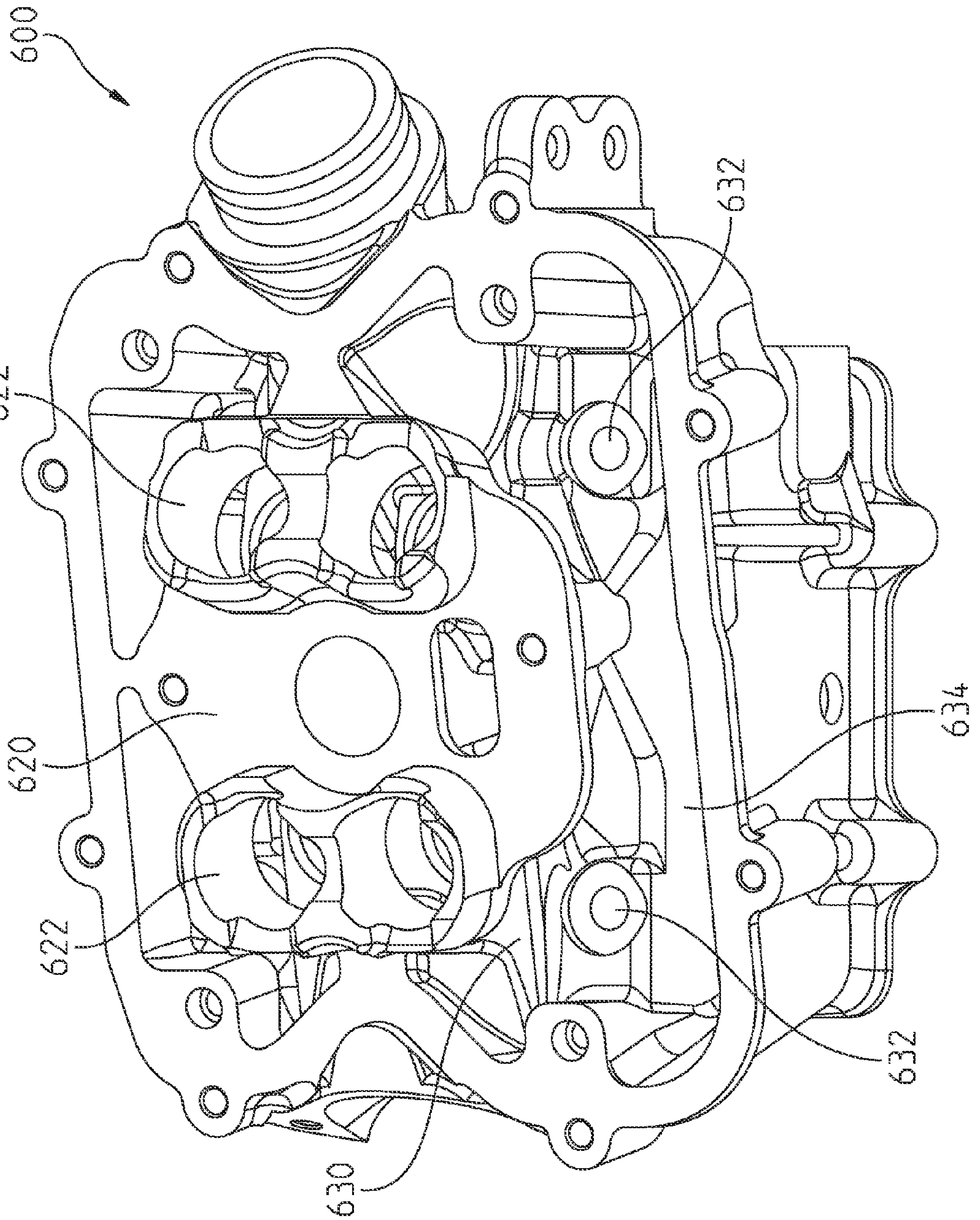


FIG. 21

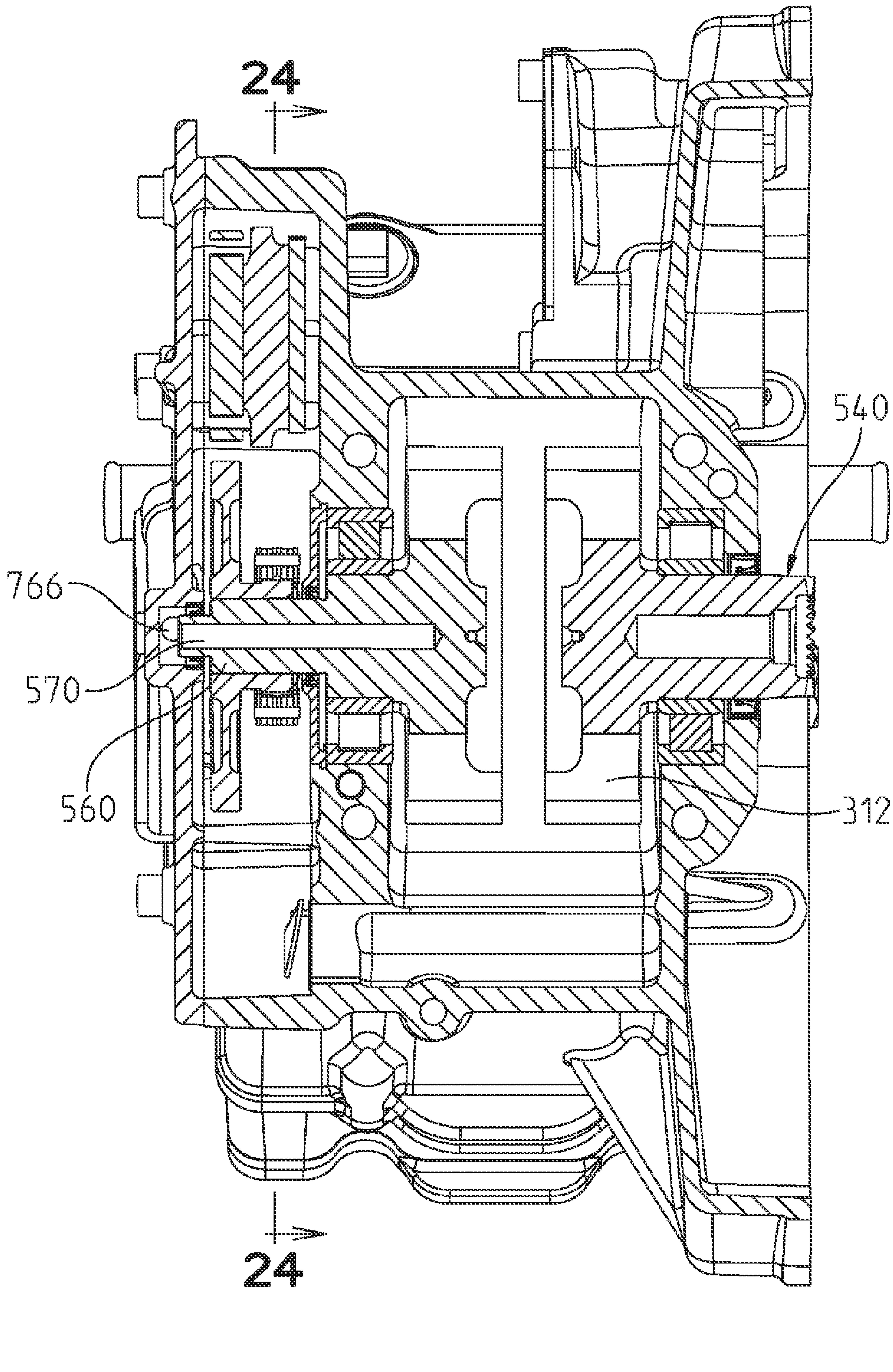


FIG. 22

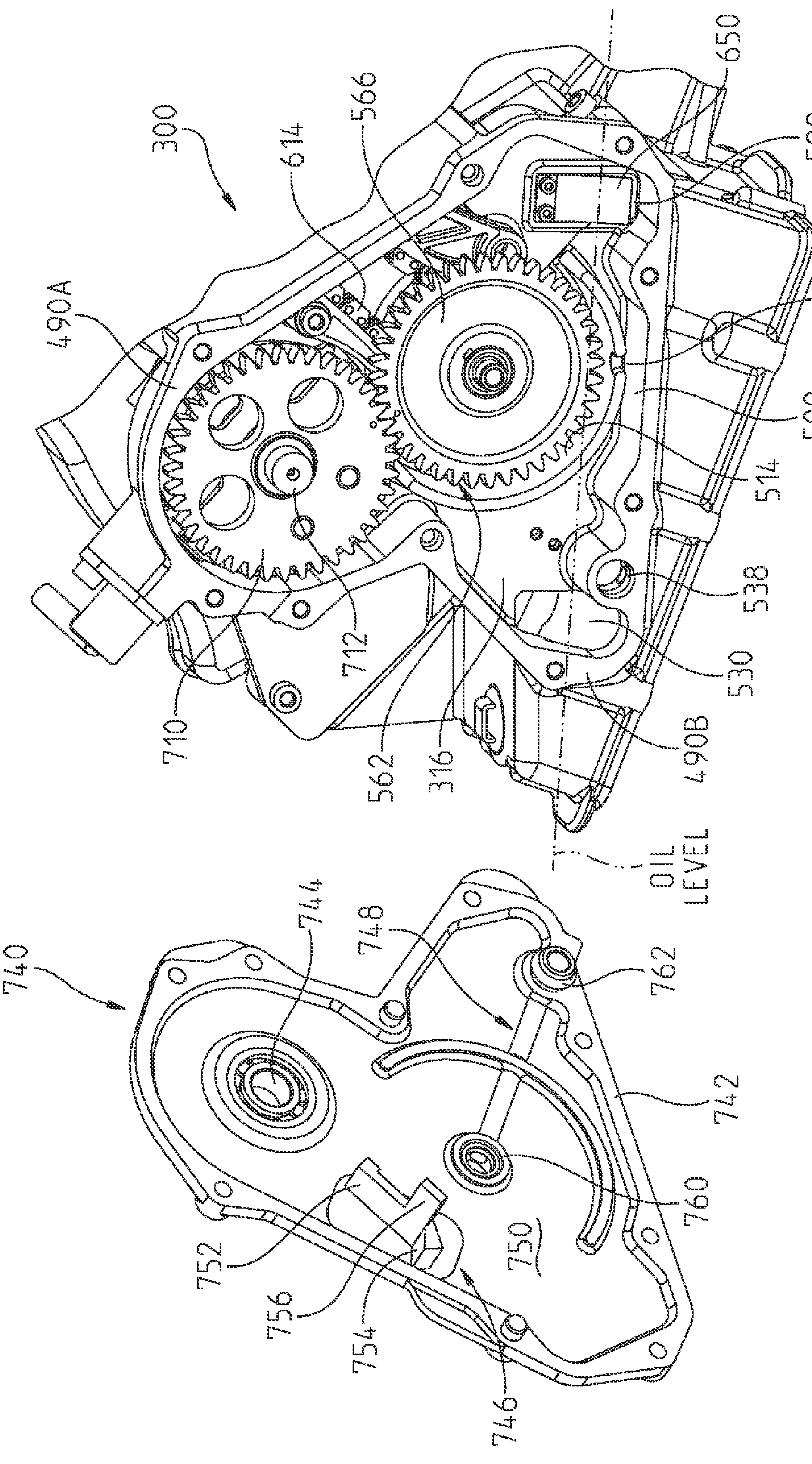

300
490A
614
566
650
522
516
500
514
538
530
490B
316
562
712
710
OIL LEVEL
740
744
748
762
742
760
750
752
756
754
746

FIG. 23

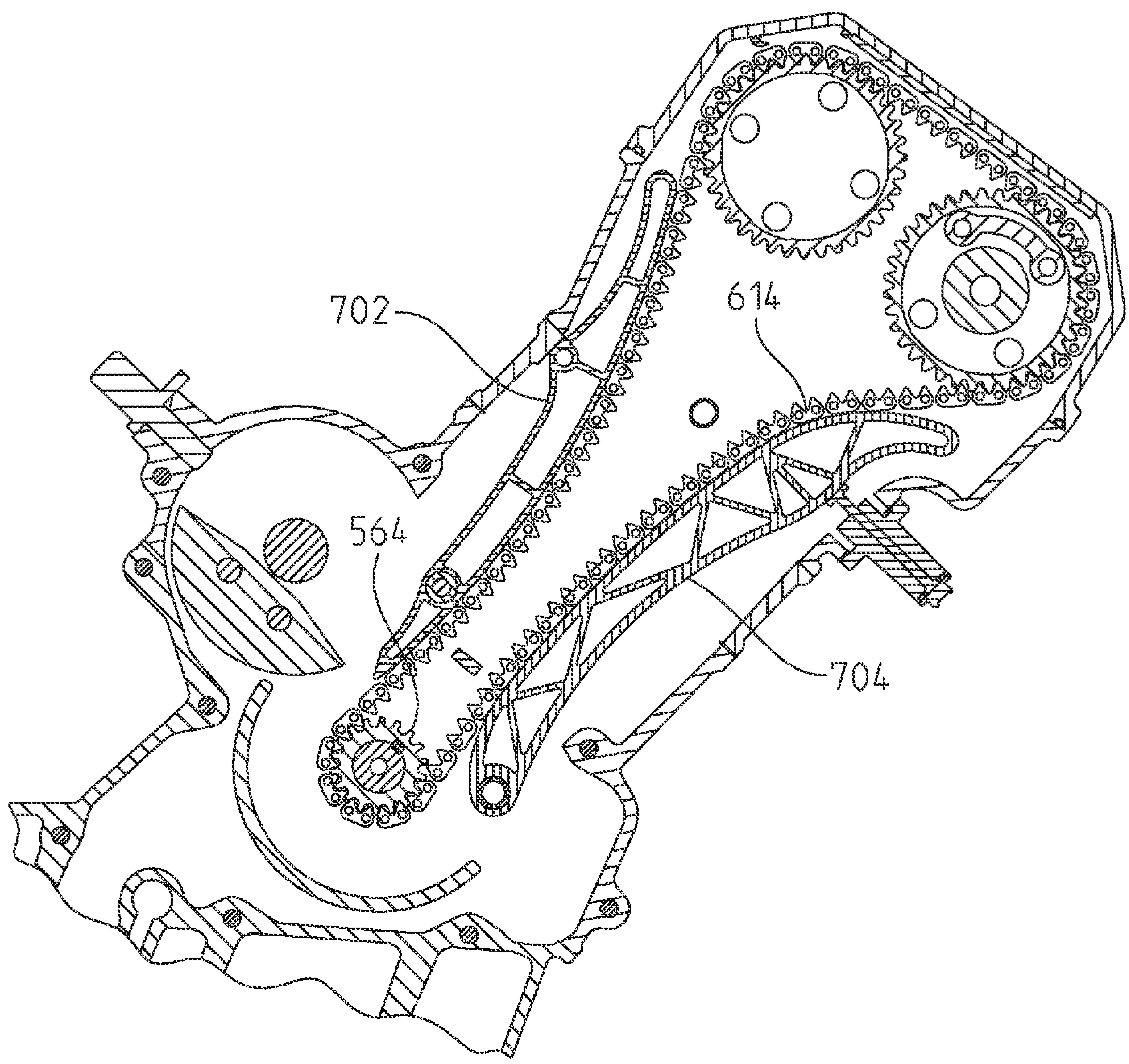


FIG. 24

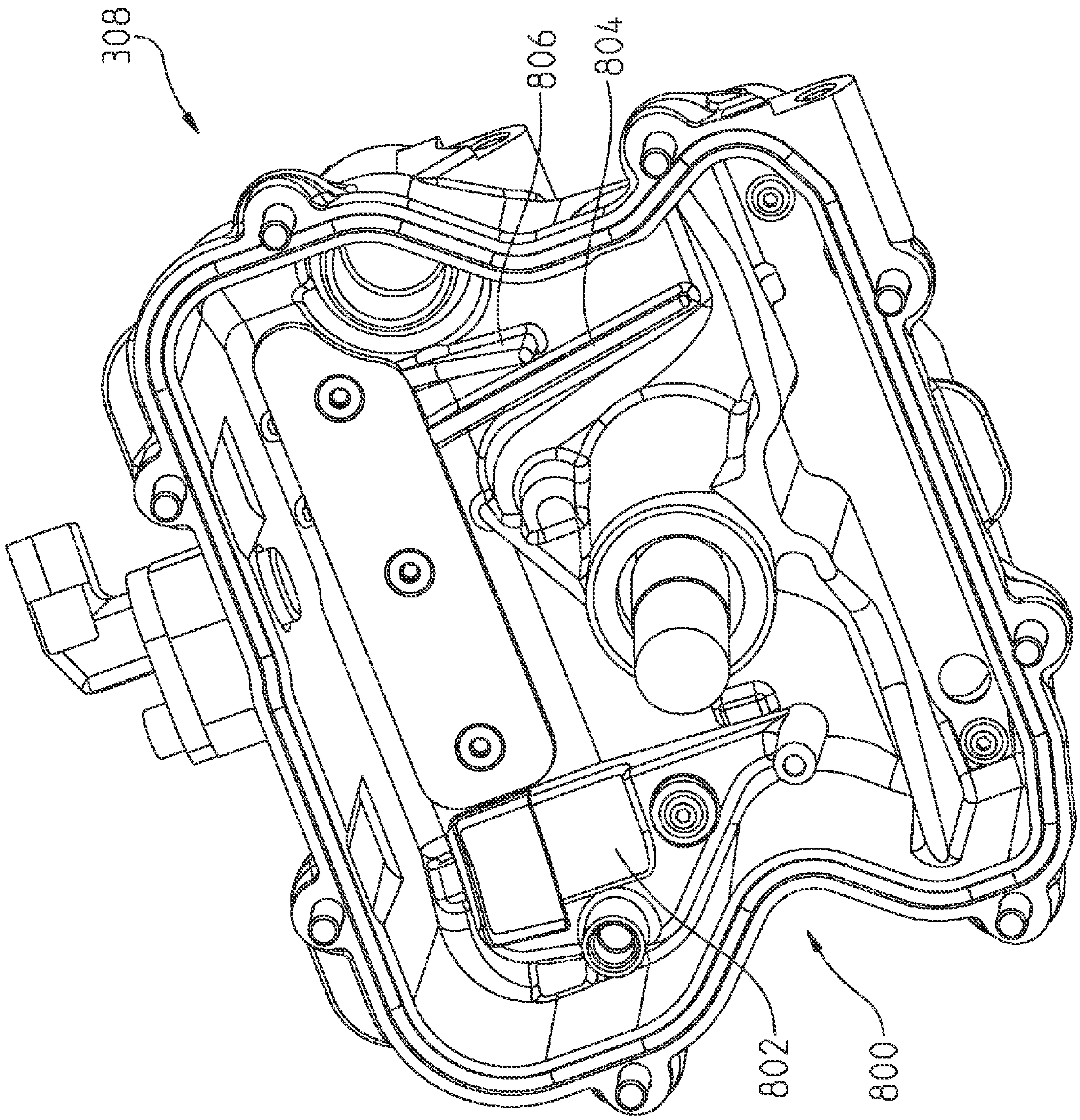


FIG. 25

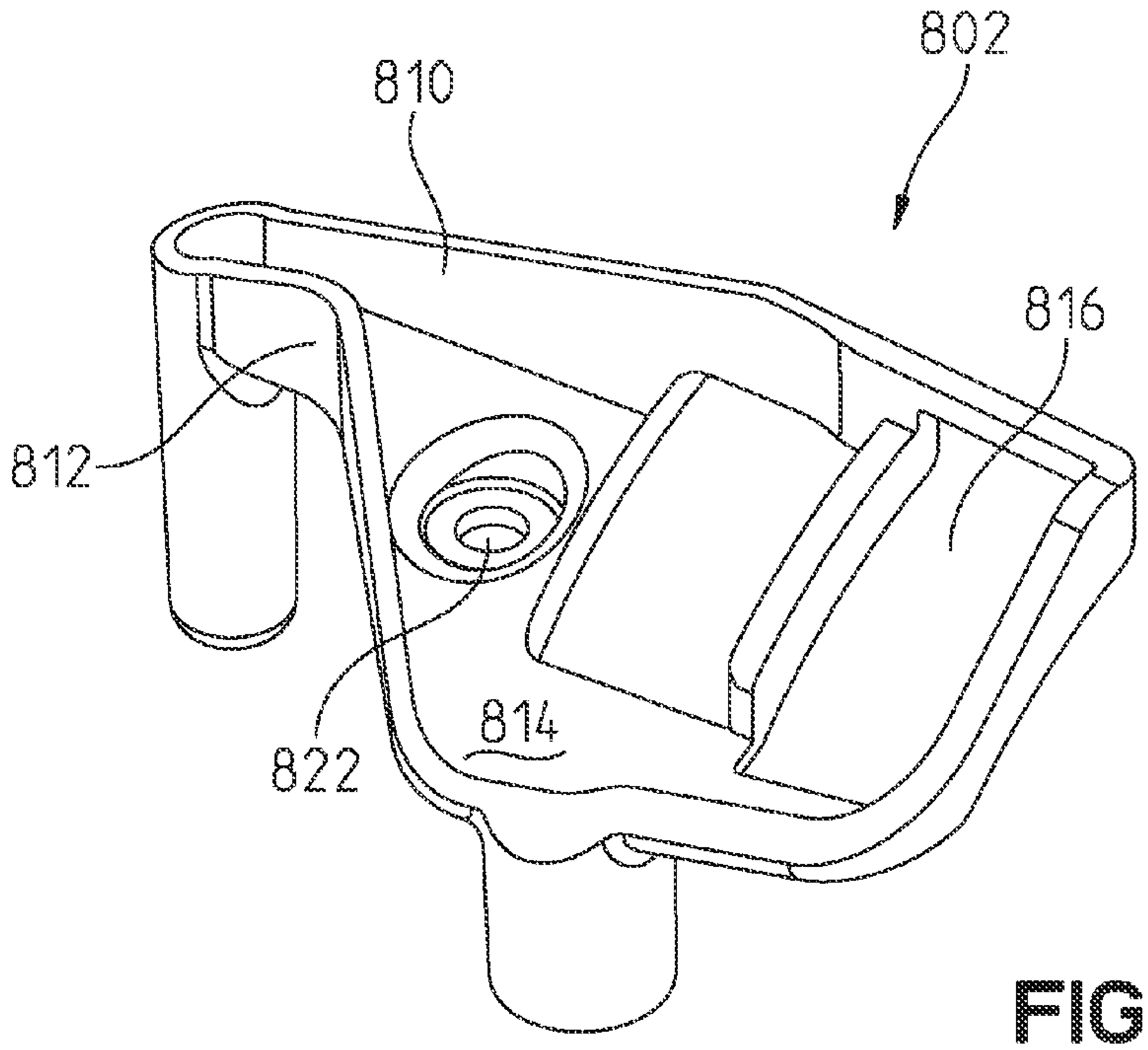


FIG. 26

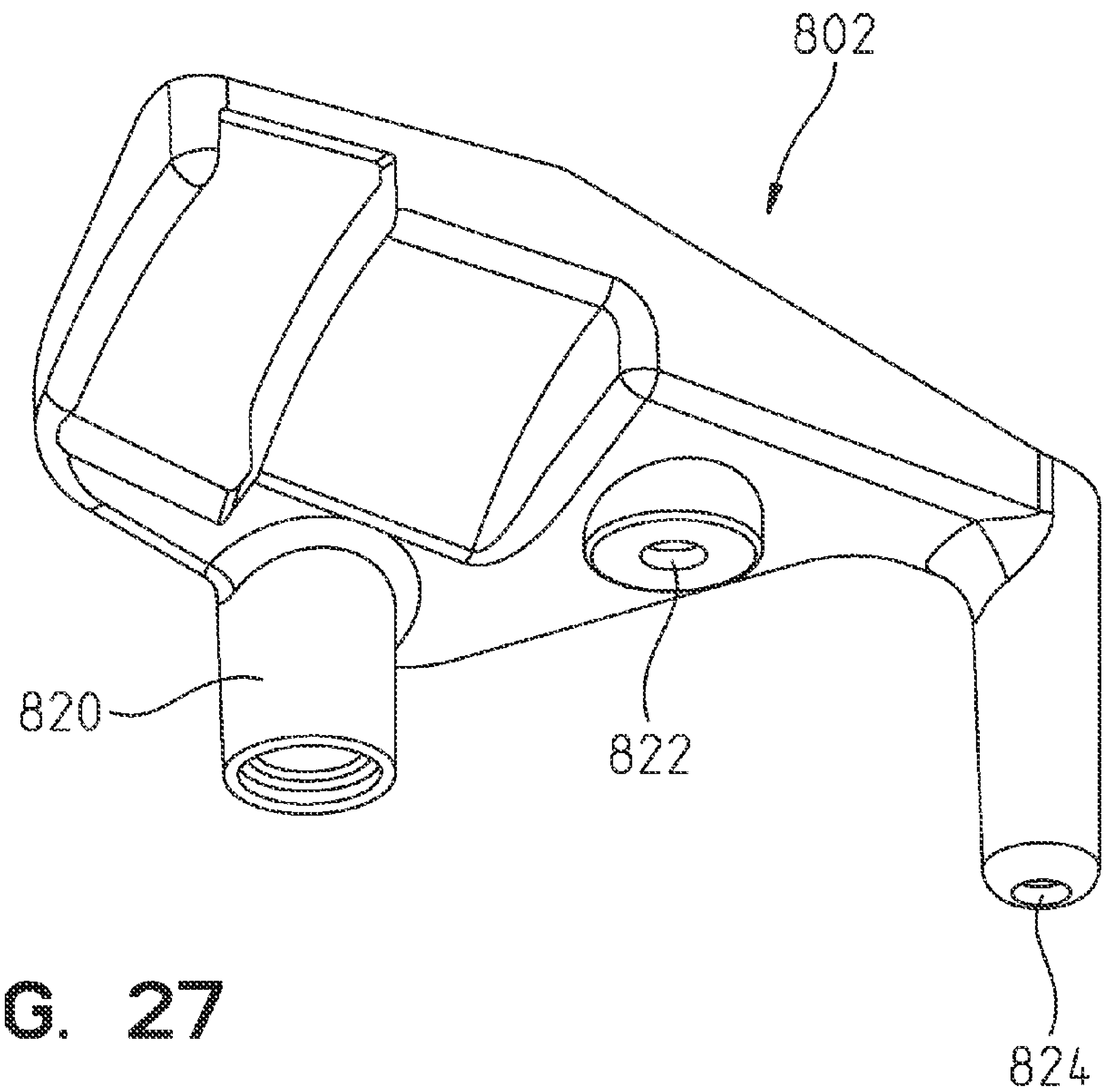


FIG. 27

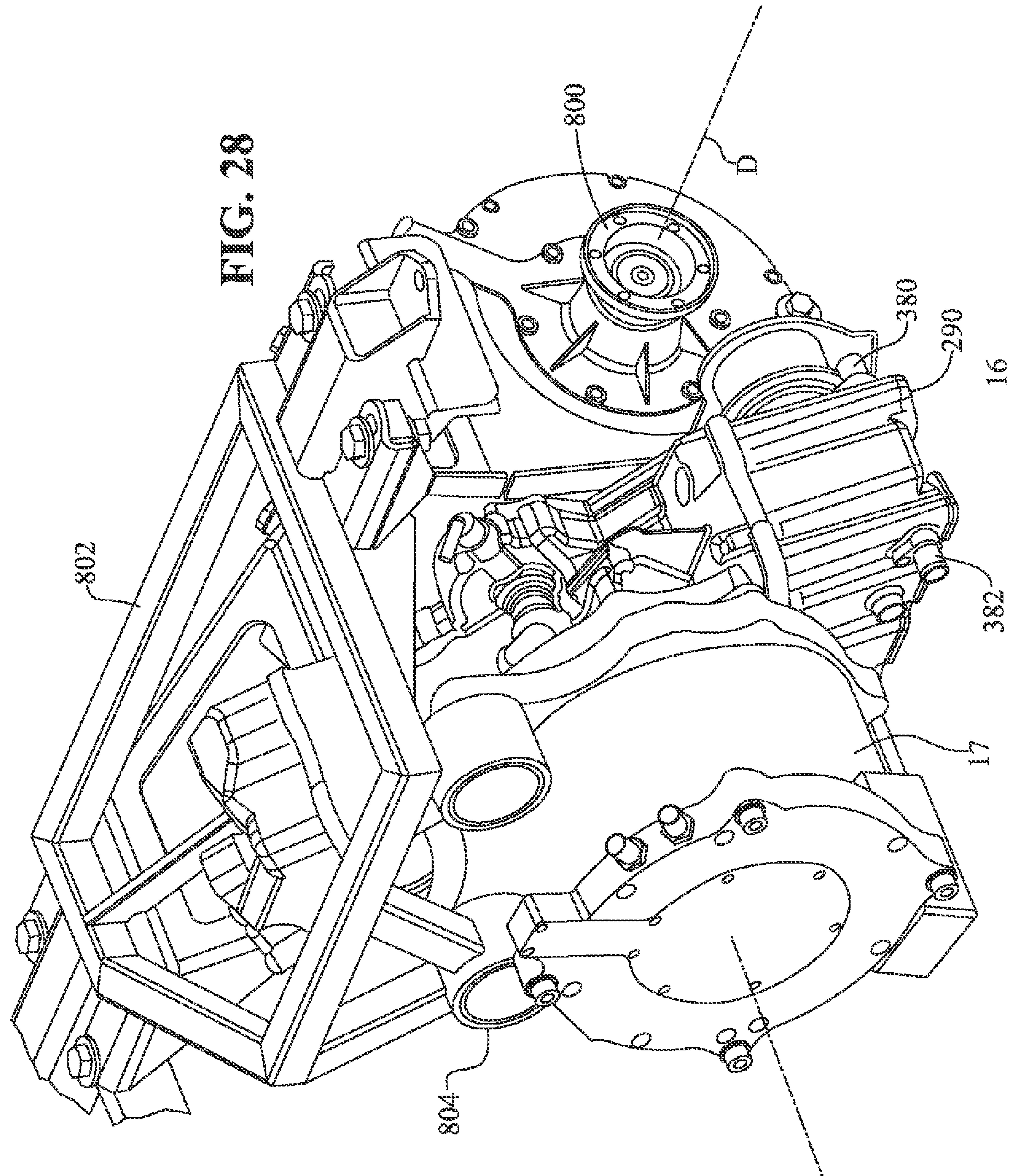


FIG. 28

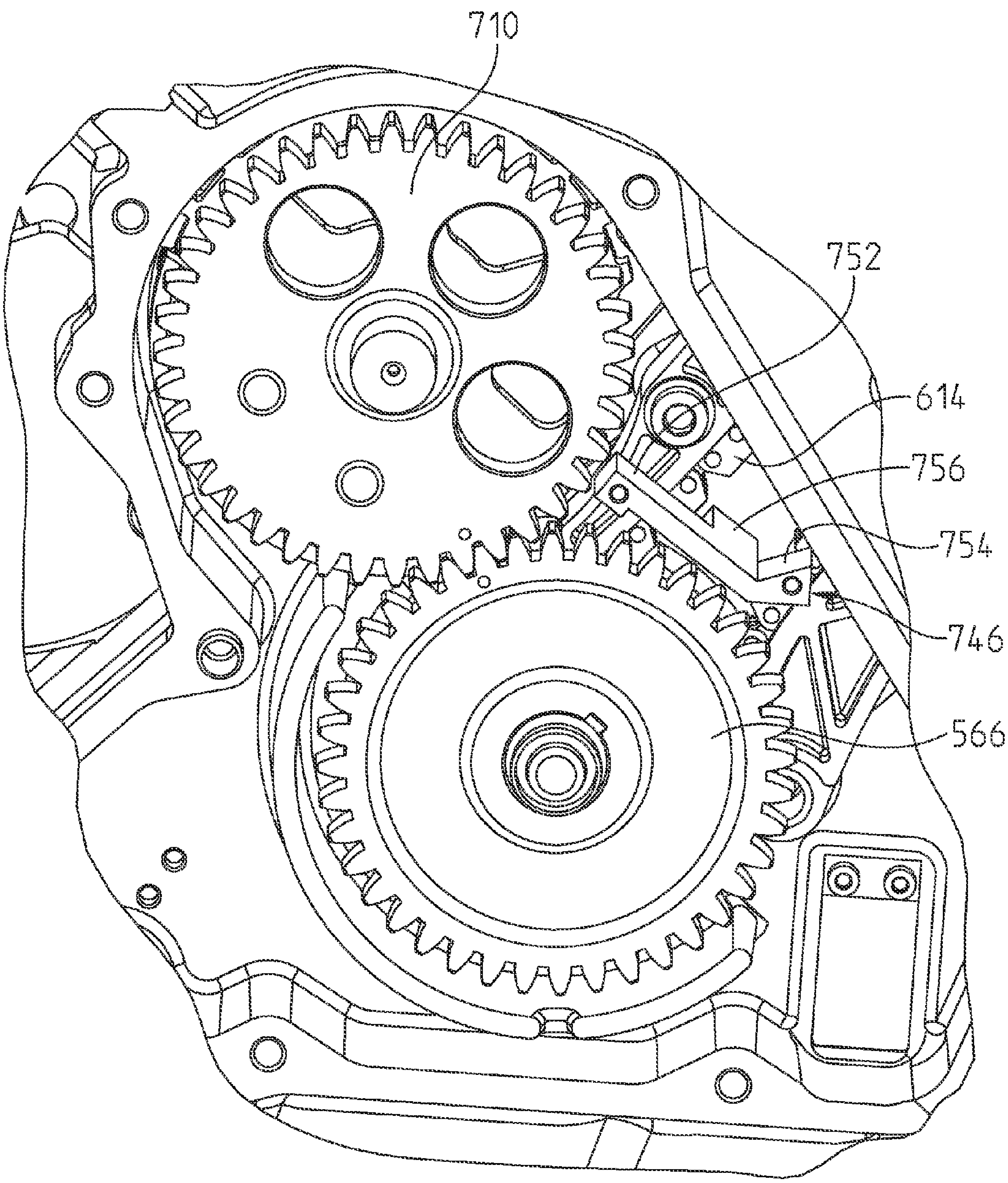


FIG. 29

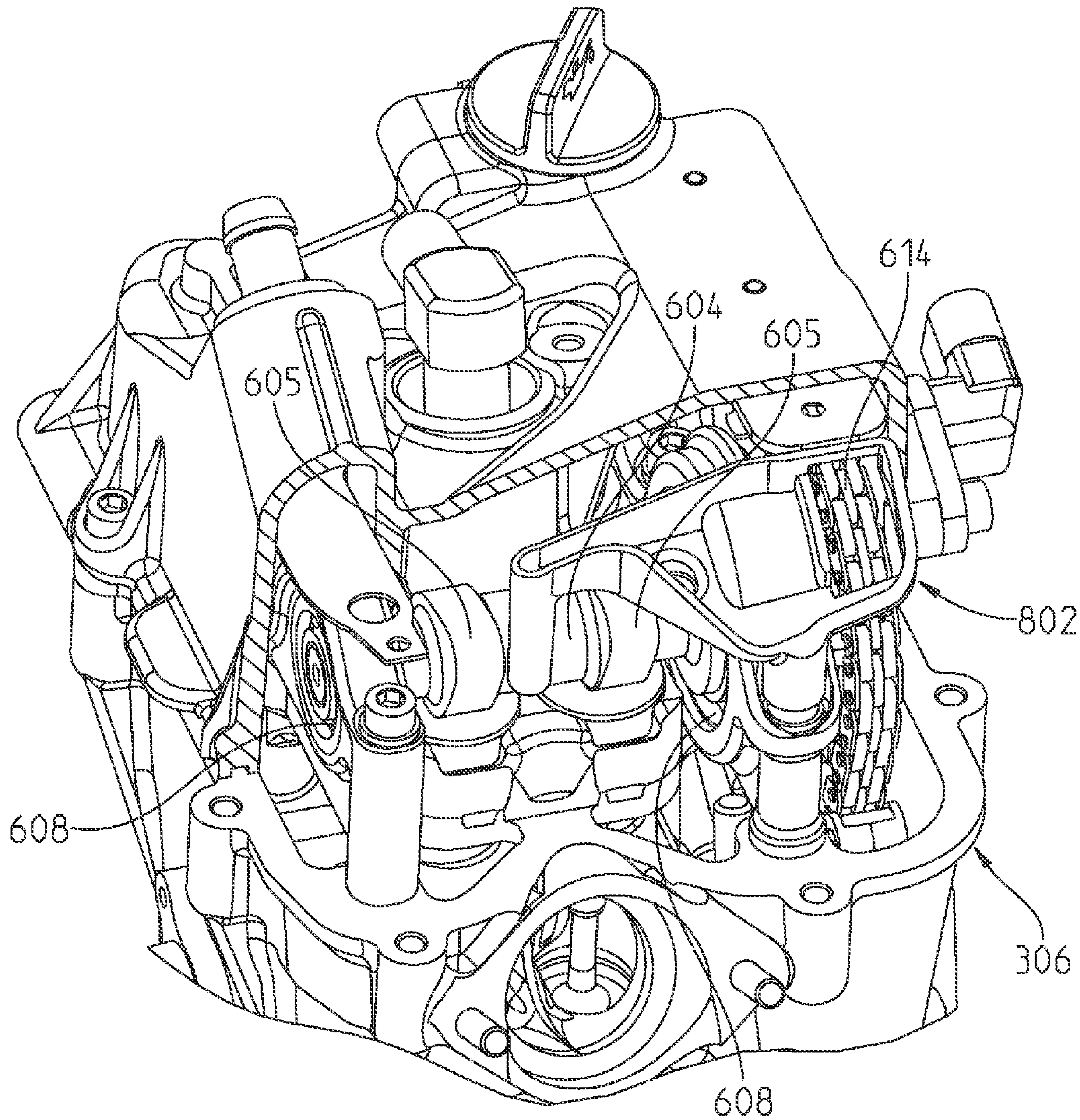


FIG. 30

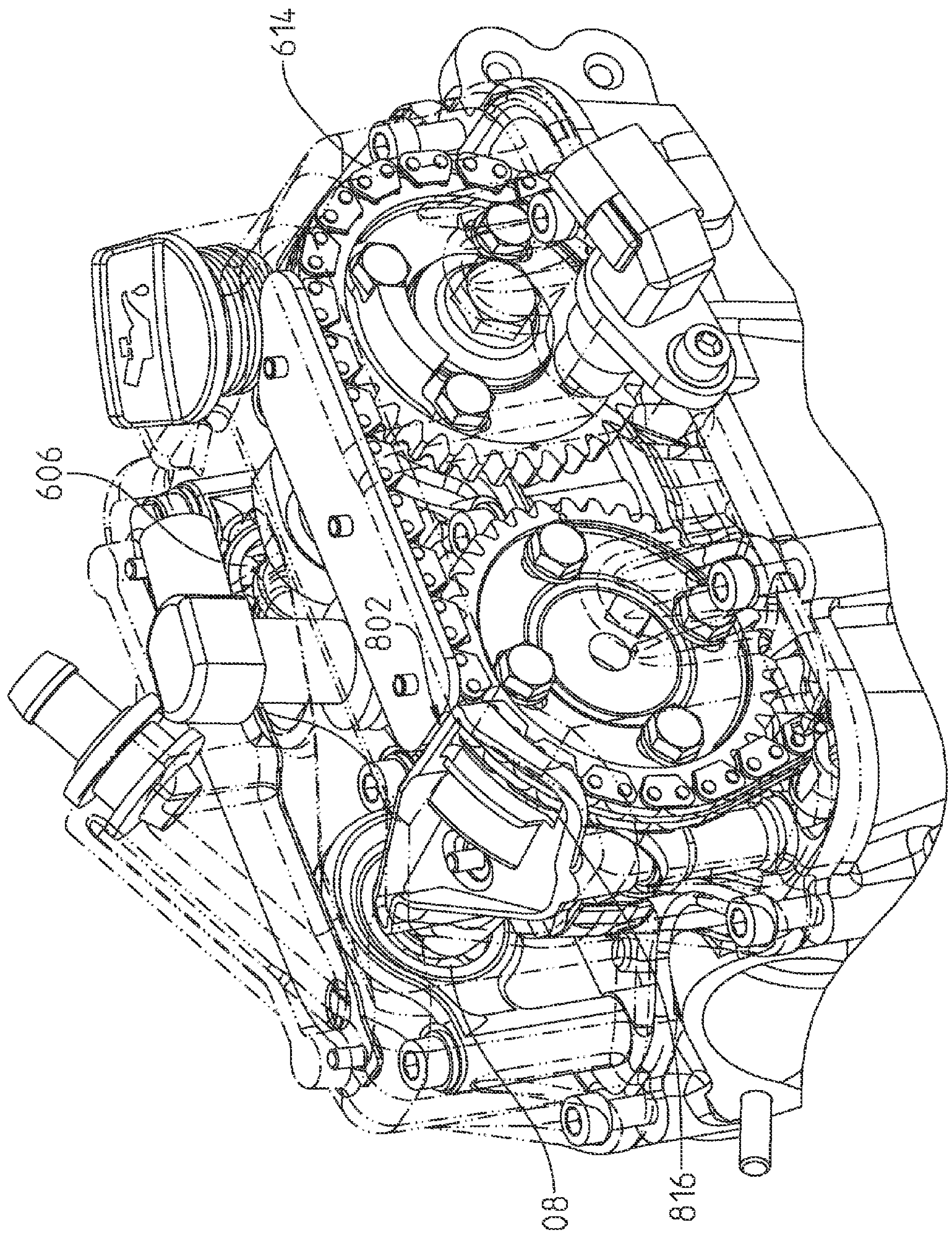


FIG. 31

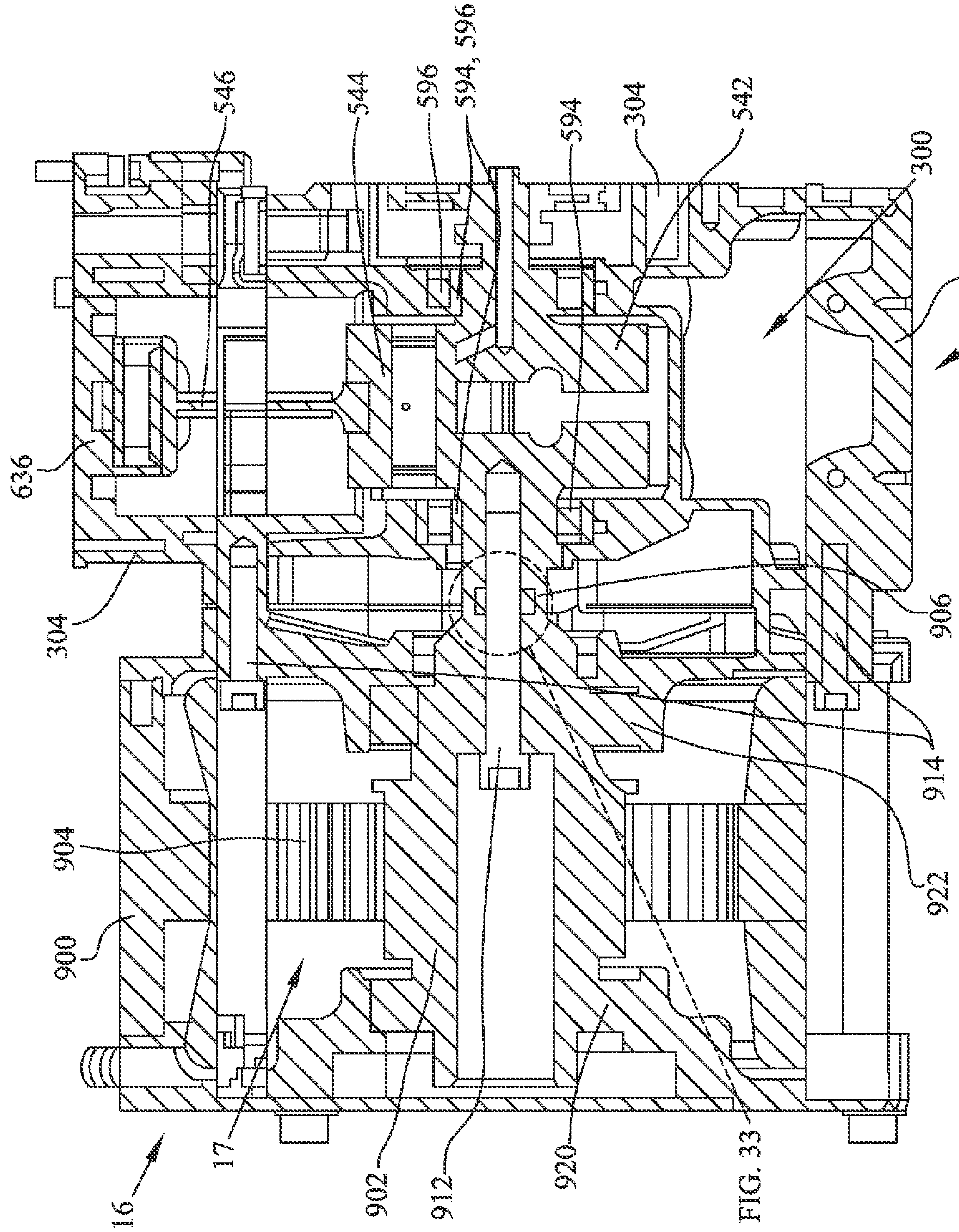

546
544
596
594, 596
594
304
542
300
302
290
636
304
906
914
922
904
900
17
16
902
912
920
FIG. 33

FIG. 32

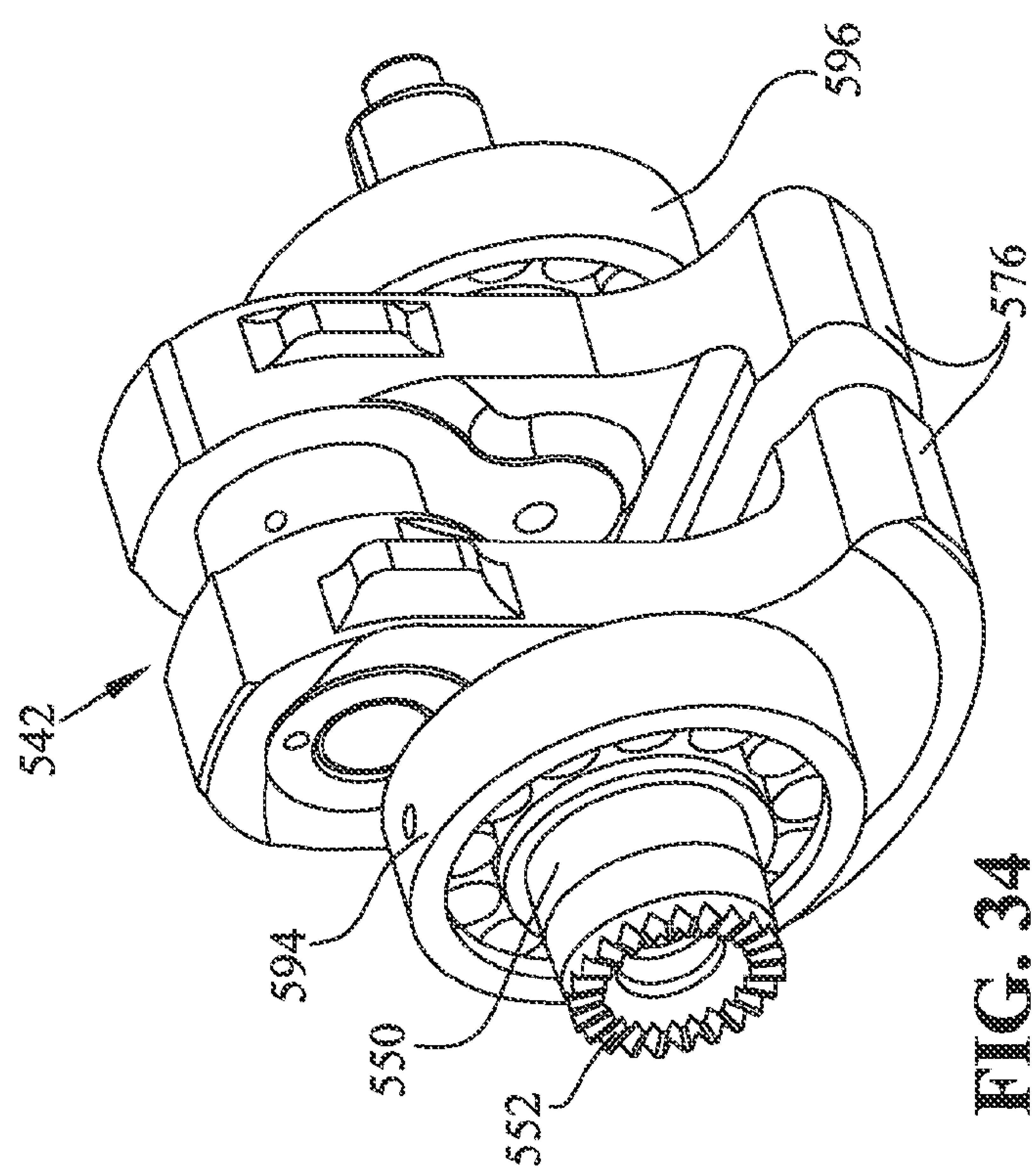


FIG. 34

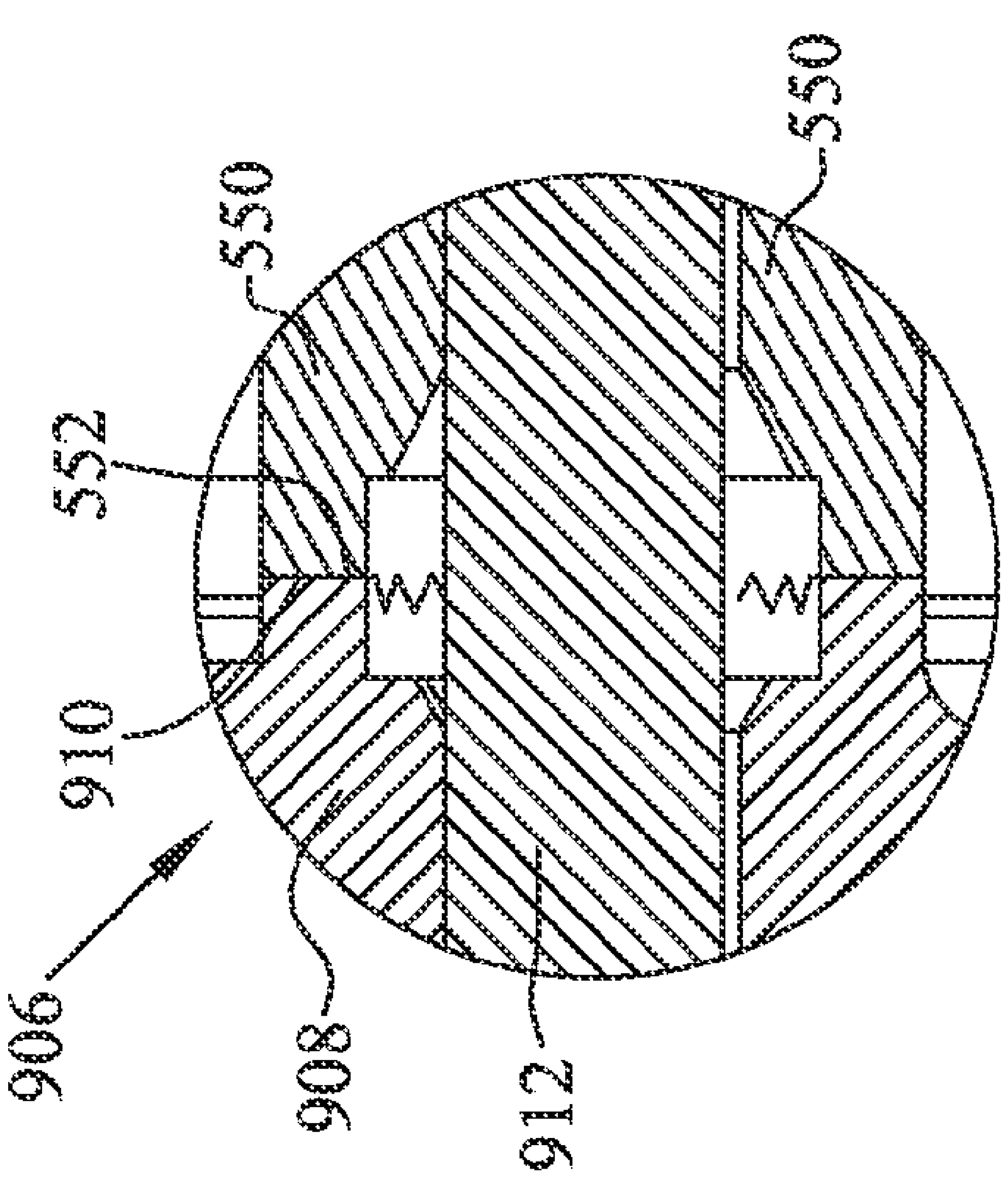


FIG. 33

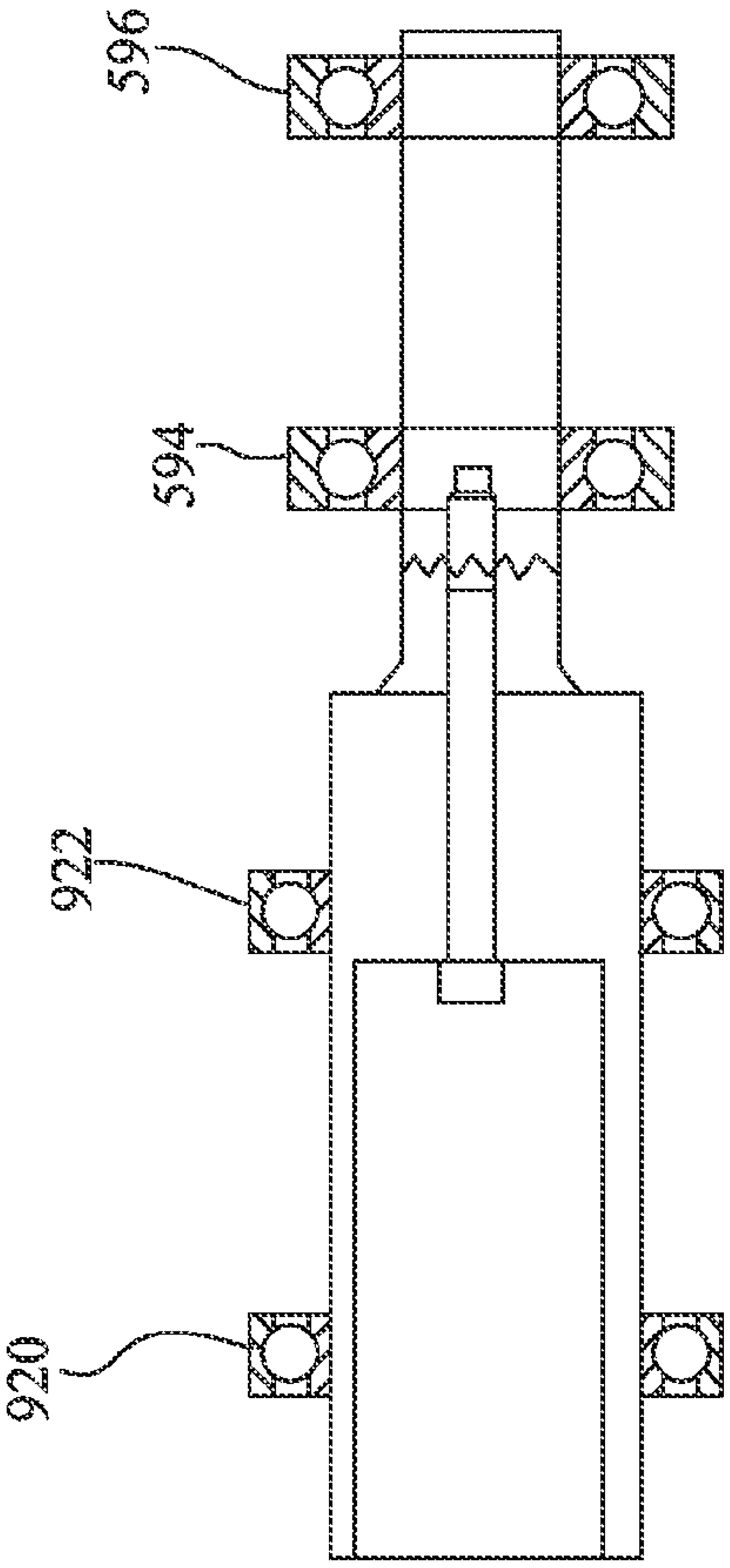


FIG. 35A

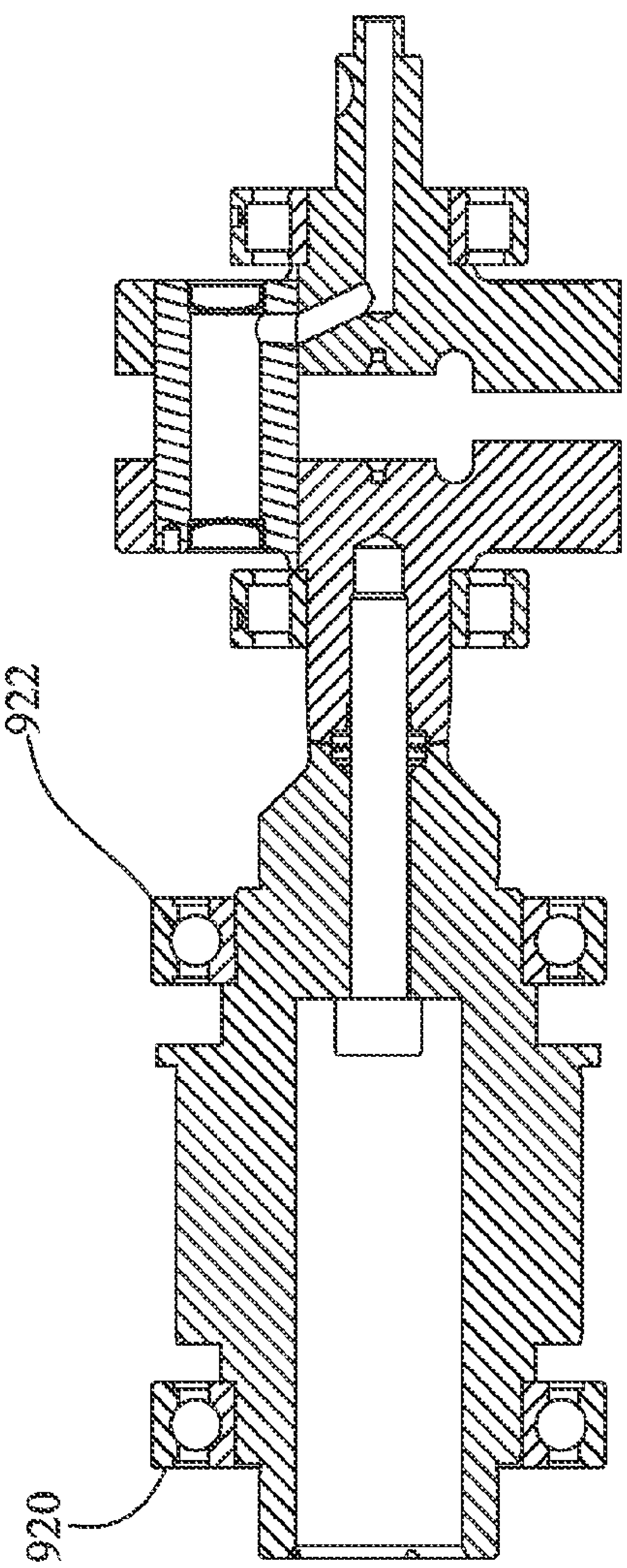


FIG. 35B

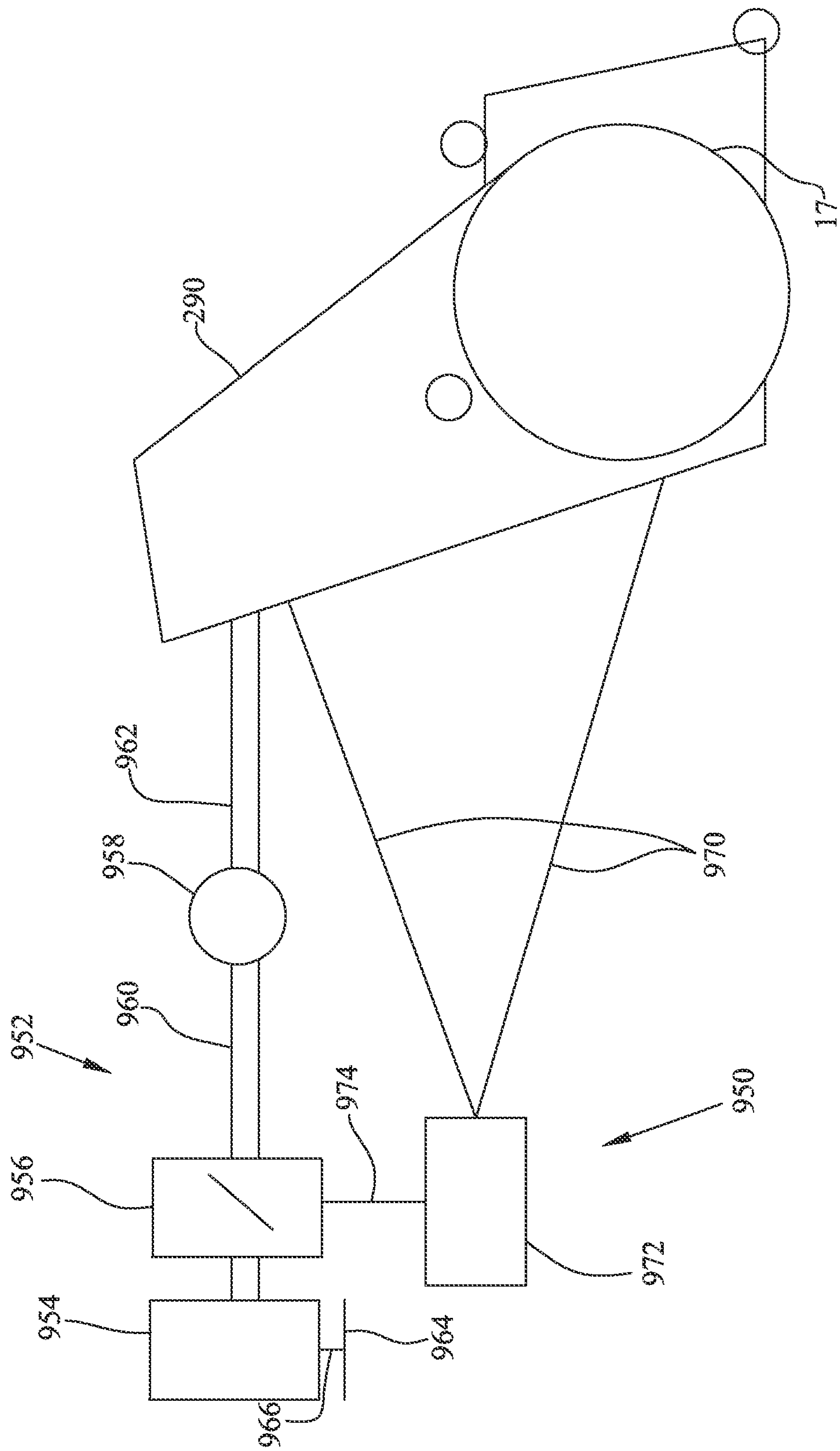


FIG. 36

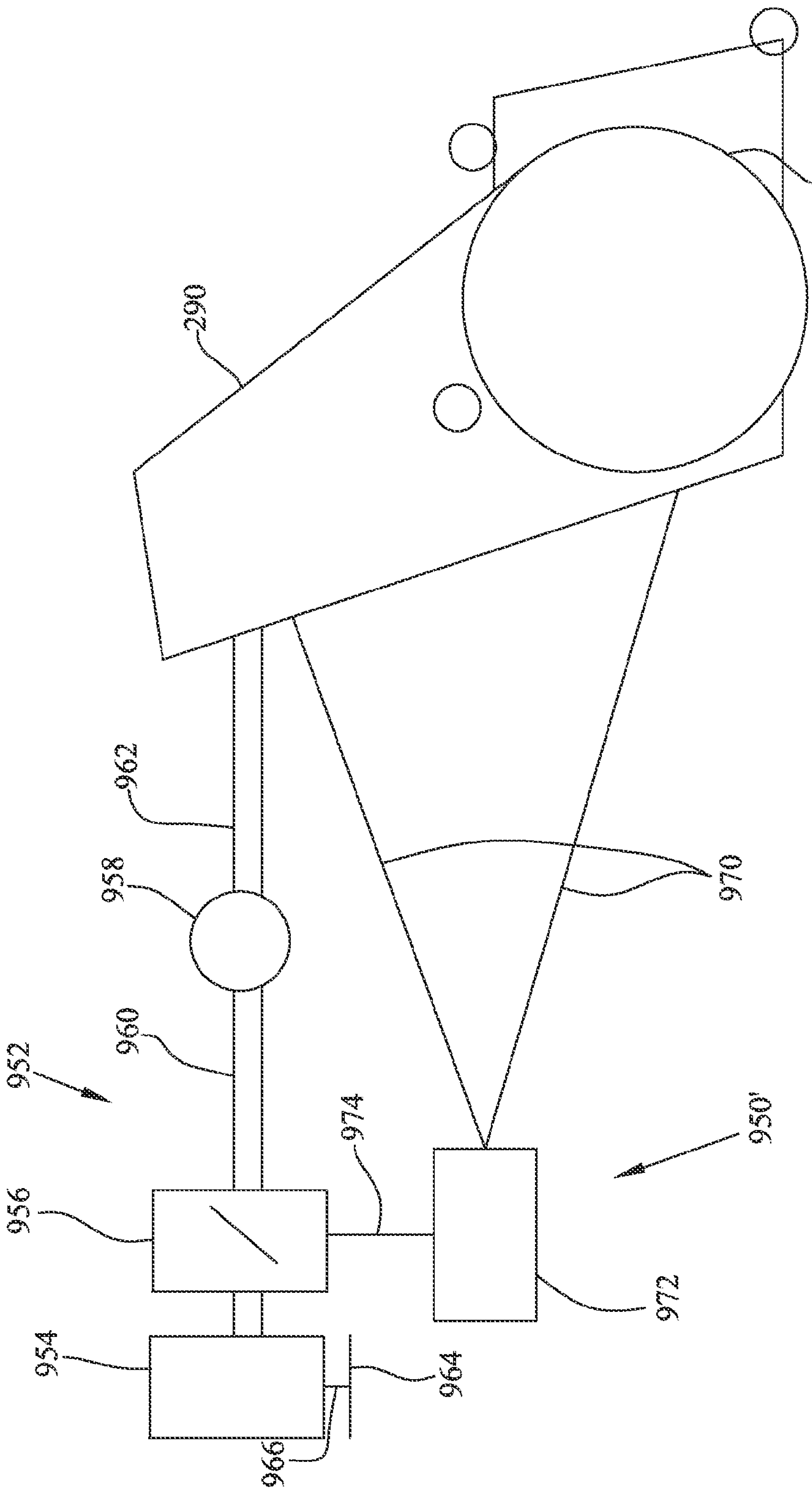


FIG. 37

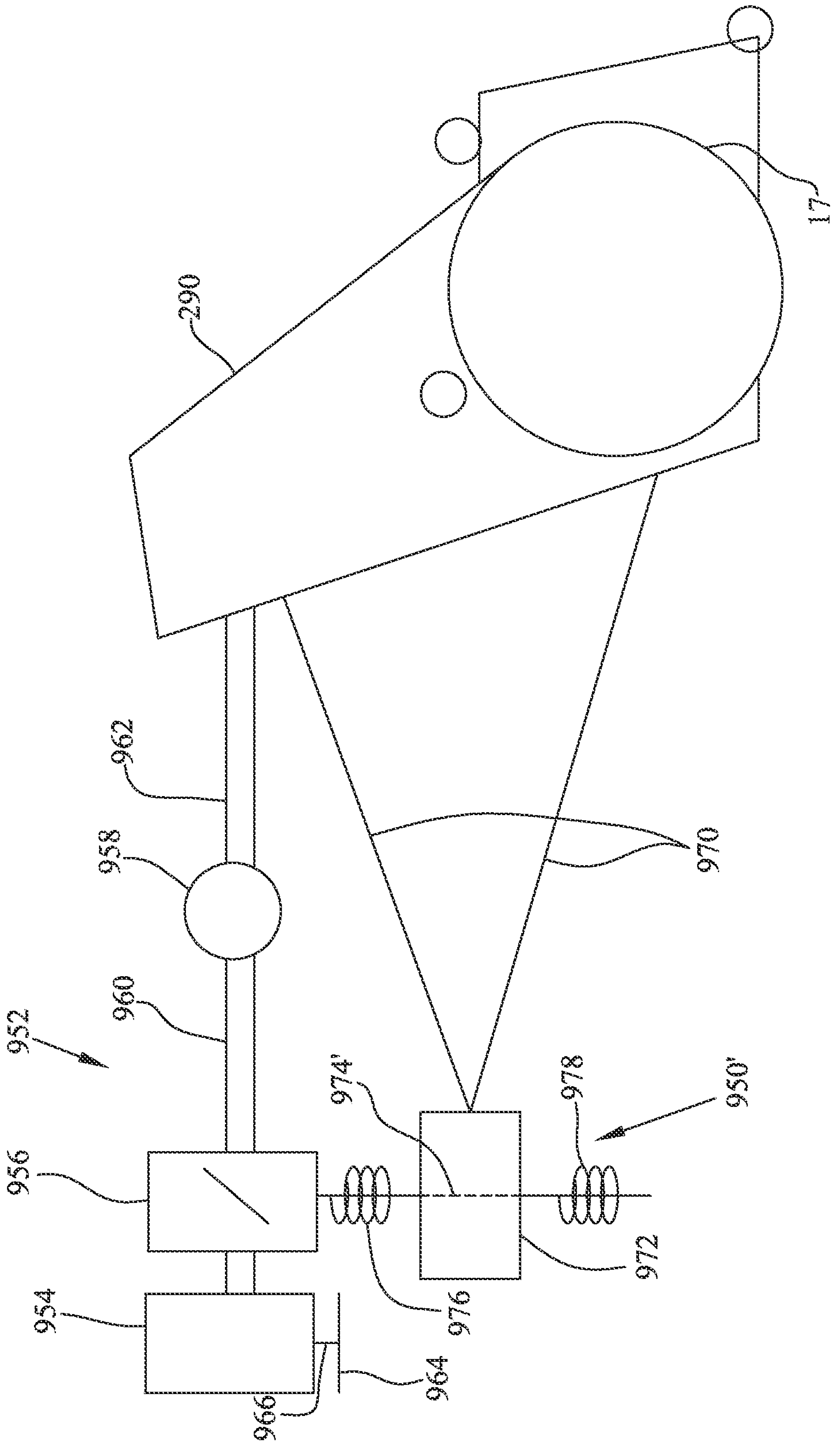


FIG. 38

ELECTRIC VEHICLE AND ON-BOARD BATTERY CHARGING APPARATUS THEREFORE

FIELD OF THE INVENTION

The subject disclosure relates to electric vehicles and a charging system therefore, and in particular, an onboard engine generator for charging the battery packs. The vehicle has extended operating range with coupled combustion engine, whereby it concerns a serial hybrid electric vehicle according to the EC-Directives.

BACKGROUND OF THE INVENTION

Electric vehicles are known having battery packs which drive an electric motor which in turn drives the vehicle wheels. Two types of vehicles are known using electric motors, the first is a hybrid electric vehicle where the vehicle includes an electric motor and an onboard fuel driven engine, where the engine is used to drive the wheels under certain vehicle circumstances.

Another type of electric vehicle also has an onboard fuel driven engine, but the engine is only used to drive a generator, which in turn charges the batteries. The latter type arrangement is referred to as range extender as the onboard engine/generator extends the range that the vehicle can travel on the battery pack before a complete recharge.

With this type of hybrid vehicle, also called electric vehicle with Range Extender, a combustion engine is coupled to an electric machine acting as a generator. The combustion engine delivers its power to the generator, which transforms the rotary motion into electric energy and supplies it to the battery to extend the range (travelling distance of a vehicle without external charge). Alternatively, the electrical energy could be connected to an electric traction motor of the vehicle. In this manner the combustion engine can be operated with a very good efficiency in all operating aspects, which has a positive effect on CO_2 emissions and fuel consumption of the aggregate. Multiple aspects of a range extender design and operation in a vehicle are addressed in this application.

A first factor of such aggregates is the coupling of the combustion engine to the generator, because the high combustion power of the engine causes substantial rotary imbalances and deformation on the crank shaft. In general, in order to couple a generator to a combustion engine, several solutions are known today, whereby the design of the generator plays an important role. The known solutions, e.g. according to DE 197 35 021 A1 or DE 10 2007 024 126 A1, concern applications in so-called parallel hybrid vehicles which have a complex coupling system in which the coupling parts are coupled axially.

Various solutions for the connection of the generator shaft with the crank shaft may be envisaged, for example an elastomer coupling could be provided, which however requires very much space axially as well as radially, and large tolerances must be chosen. These couplings also cannot absorb the required increasing dynamic torque.

Other connections include connection of the shafts through a cone or tapered coupling. The connections provide a rigid connection, but need space in length and diameter in order to have enough rigidity. Furthermore, axial tolerances are problematic because during the assembly, the mounting position dependent on the tightening torque cannot be exactly determined. Assembly and removal are also made more difficult.

Other connections include connection of the shafts through internal teeth. These connections however are complex to

manufacture; the generated momentum provoke a mechanical play and running noise if a thrust tolerance is used; assembly and removal are problematic with crimp connections; and assembly length/space requirements are relatively high.

Based on this state of the art, it is an object of the invention to provide a serial hybrid electric vehicle in which the connection between the combustion engine and the generator is very precisely adjusted and has a torsion-resistant design, yet enabling both weight savings and easy assembly.

Another object is to enable an efficient length adjustment of the generator shaft and the crank shaft in case of variations in temperature.

Another object is to enable the generator to serve as the flywheel mass of the engine, reducing both the cost and the weight.

Another object is to provide minimum weight to the engine by eliminating such peripheral components as a tradition oil pump. Rather, a method of providing a "pump" from suction created during the compression stroke is shown herein.

Another object is to provide components within the engine requiring minimal lubrication.

Another object is to provide an engine design having a "run-ready" condition.

Another object is to provide an optimized heating/cooling system for the range extender and vehicle.

With the present design in accordance with the drawings, the generator is suitable for the mounting to different engines, whereby the coupling can in principle be made by any chosen connection of the shafts and the housing. Engine and generator are independent and are connected by a connecting member. For a single-cylinder engine with a very short crank shaft, this design is the most sensible solution because of the separate bearing of the generator rotor allows the air gap in the generator to be kept small in order to achieve a high efficiency. The bending moment in the crank shaft during combustion, as well as the bearing clearances on the short distance between the bearings can in an appropriate arrangement be carried by the generator bearing, thus preventing contact of the rotor and the housing.

Depending on the design and the stability of the shaft connection between the combustion engine and the generator, the generator may serve as a flywheel mass for the combustion engine, which is however not without difficulty because of the generated momentum, but is solved, with the solution at hand.

The present disclosure relates to an engine/generator and the control mechanism for a range extender engine.

In one embodiment, a serial hybrid electric vehicle is coupled with a combustion engine which serves to extend the operating range. The combustion engine is coupled to the generator of the range extender by a self-centering spur gearing.

In another embodiment of the invention, a serial hybrid electric vehicle is coupled with combustion engine which serves to extend the operating range. A crankshaft of the engine is fixedly connected to a shaft of the generator. A fixed bearing and a first floating bearing are located on the side of the generator and the bearings on the side of the engine are configured as floating bearings in order to absorb the length extensions of the shafts caused by temperature influence.

In another embodiment of the invention, a combustion engine, comprises a crankcase defining a journal area and an oil sump; a cylinder communicating with the crankcase; a cam chain chamber discrete from the crankcase; a crankshaft journalled in the journal area of the crankcase, with a first end extending into the cam chain chamber and a second end extending through the crankcase; a piston positioned in the cylinder; a connecting rod coupling the piston to the crankshaft; a head above the cylinder having at least one cam therein operating valves in the head; a first gear positioned on the crankshaft first end and positioned in the cam chain chamber; a second gear positioned on an end of the cam; a chain entrained around the first and second gear; a passageway defined between the oil sump and the crankshaft; wherein, when the piston is moving from a bottom dead center position to a top dead center position, a vacuum is created, siphoning oil through the passageway to lubricate at least a portion of the crankshaft.

In another embodiment of the invention, a combustion engine, comprises a crankcase defining a journal area and an oil sump; a cylinder communicating with the crankcase; a cam chain chamber discrete from the crankcase; a crankshaft journalled in the journal area of the crankcase, with a first end extending into the cam chain chamber and a second end extending through the crankcase; a piston positioned in the cylinder; a connecting rod coupling the piston to the crankshaft; a head above the cylinder having at least one cam therein operating valves in the head; a first gear positioned on the crankshaft first end and positioned in the cam chain chamber; a second gear positioned on an end of the cam; a chain entrained around the first and second gear; a port communicating between the crankcase and the cam chain chamber; and a valve allowing the flow of blow by gases and compressed gases into the cam chain chamber when the piston is moving from a top dead center position to a bottom dead center position.

In another embodiment of the invention, a combustion engine comprises a vehicle, comprising: an electric propulsion drive assembly; a first cooling circuit for the electric propulsion drive assembly; an engine, including a crankcase having an oil sump; and a pre-heater for the oil sump in fluid communication with the first cooling circuit for pre-heating engine oil.

In another embodiment of the invention, a combustion engine comprises a crankcase having an oil sump; and a pre-heater for pre-heating engine oil in the oil sump, the pre-heater being integrated with the oil sump of the crankcase.

In another embodiment of the invention, a combustion engine comprises a crankcase defining a journal area and an oil sump; a cylinder communicating with the crankcase; a cam chain chamber discrete from the crankcase; a crankshaft journalled in the journal area of the crankcase, with a first end extending into the cam chain chamber and a second end extending through the crankcase; a piston positioned in the cylinder; a head above the cylinder having at least one camshaft therein operating valves in the head; a first gear positioned on the crankshaft first end and positioned in the cam chain chamber; a second gear positioned on an end of the cam; a chain entrained around the first and second gear; and an oil distribution mechanism for distributing oil in the oil sump onto the cam chain for delivering lubrication oil to the head.

In another embodiment of the invention, a combustion engine comprises a crankcase defining a journal area and an oil sump; a cylinder communicating with the crankcase; a cam chain chamber discrete from the crankcase; a crankshaft journalled in the journal area of the crankcase, with a first end extending into the cam chain chamber and a second end extending through the crankcase; a piston positioned in the cylinder; a head above the cylinder having at least one camshaft therein operating valves in the head; a first gear positioned on the crankshaft first end and positioned in the cam chain chamber; a second gear positioned on an end of the cam; a chain entrained around the first and second gear; and an oil distribution member within the head to deliver oil to the cam lobes.

In another embodiment of the invention, a control system is provided for an electric vehicle, where the electric vehicle includes a drive axle coupled to a chassis. The control system comprises an engine generator including an electrical machine driven by an engine, the engine generator being configured to generate electrical power; a controller configured to electronically control the engine of the engine generator; an electric motor configured to drive the drive axle of the electric vehicle; a battery configured to drive the electric motor and to receive the electrical power generated by the engine generator; and a mode selection device in communication with the controller for selecting one of a plurality of operating modes of the engine generator, the plurality of operating modes providing variable rates of electrical power generation.

An inventive method of controlling an engine of an electric vehicle including a generator driven by the engine and an electric motor driven by an onboard battery, the method includes the steps of: monitoring a vehicle speed of the electric vehicle; starting the engine of the electric vehicle when the vehicle speed increases to a first predetermined threshold; generating electrical power with the generator for use by the electric vehicle; and stopping the engine of the electric vehicle when the vehicle speed decreases to a second predetermined threshold.

An inventive method of controlling an engine of an electric vehicle including a generator driven by the engine and an electric motor driven by an onboard battery, the method includes the steps of: providing a vehicle control unit for controlling an electrical system of the electric vehicle, the electrical system including the electric motor and the battery; driving the electric motor with the battery; monitoring a plurality of parameters of the battery with the vehicle control unit, the plurality of parameters including at least one of a voltage level, a charge level, and a temperature level; starting the engine of the electric vehicle when each of the plurality of parameters of the battery are below a predetermined minimum threshold; generating electrical power with the generator for use by the electric vehicle; and charging the battery of the electric vehicle with the generated electrical power.

An inventive method of charging a battery of an electric vehicle, the electric vehicle including a generator driven by an engine and an electric motor driven by the battery, the electric motor being configured to drive a drive axle of the electric vehicle to move the electric vehicle. The method includes the steps of providing a regenerative braking system with the electric vehicle, the regenerative braking system being configured to transfer kinetic energy of the electric vehicle to the electric motor to rotate the electric motor in a reverse direction; rotating the electric motor in a forward direction with electrical power from the battery to move the electric vehicle; generating a first electrical current with the generator, the first electrical current being routed to the battery; rotating the electric motor in a reverse direction with the regenerative braking system to slow movement of the electric vehicle and to generate a second electrical current, the second electrical current being routed to the battery; charging the battery with the first and second electrical currents; monitoring the first and second electrical currents during the charging step to determine a total electrical current supplied to the battery; and removing the first electrical current from the battery upon the total electrical current exceeding a first predetermined threshold.

In another embodiment, an electric vehicle, comprises a chassis; a drive axle coupled to the chassis; an electric motor configured to drive the drive axle; a battery configured to drive the electric motor; an engine generator configured to generate electrical power and to provide electrical power generated to the battery; and a mass supported by the engine to dampen vibrations of the engine.

Finally, a method of controlling an engine of an electric vehicle, where the electric vehicle includes a generator driven by the engine, an electric motor driven by a battery, and a transmission having a plurality of gears, the method including the steps of: monitoring a vehicle speed of the electric vehicle; placing the transmission of the electric vehicle in a neutral gear; receiving a user input configured to activate the engine of the electric vehicle; starting the engine of the electric vehicle upon receipt of the user input and upon the vehicle speed of the electric vehicle being at or below a predetermined threshold value; generating electrical energy with the generator; routing the electrical energy to the battery; and charging the battery of the electric vehicle with the generated electrical energy.

The invention will now be explained in more detail in the following by means of drawings of an exemplary embodiment, where:

FIG. **1** illustrates a representative view of an exemplary electrical system of an electric vehicle according to one embodiment;

FIG. **2** illustrates exemplary control logic for controlling the range extender of the electrical system of FIG. **1**;

FIG. **3** is a graph illustrating vehicle speed versus engine speed and throttle opening percentage in an exemplary battery hold mode of the range extender of FIG. **1**;

FIG. **4** is a graph illustrating exemplary vehicle drive power consumption and an exemplary battery hold mode of the range extender of FIG. **1**;

FIG. **5** is a graph illustrating an exemplary range extended mode and an exemplary battery charge mode of the range extender of FIG. **1**;

FIG. **6** is schematic view of the vehicle system cooling system;

FIG. **7** shows a perspective view of the engine of the present embodiment;

FIG. **8** shows a perspective view of the opposite side of the engine shown in FIG. **7**;

FIG. **9** shows a side view of the engine shown in FIG. **7**;

FIG. **10** is a cross-sectional view through staggered lines **10-10** of FIG. **7**;

FIG. **11**A is a perspective view of the oil sump;

FIG. **11**B is an underside perspective view of the oil sump, partially exploded;

FIG. **12** is a cross-sectional view through lines **12-12** of FIG. **11**A;

FIG. **13** is a cross-sectional view through lines **13-13** of FIG. **11**A;

FIG. **14** is an upper partially exploded view of the crank housing from the generator mount side;

FIG. **15** is a lower partially exploded view of the crank housing from the generator mount side;

FIG. **16** is an upper partially exploded view of the crank housing from the cam chain drive side;

FIG. **17** is a lower partially exploded view of the crank housing from the cam chain drive side;

FIG. **18** shows a cut away perspective view of the crank assembly;

FIG. **19** shows an upper perspective view of the crank assembly;

FIG. **20** shows an upper perspective view of the head assembly and valve cover;

FIG. **21** is a perspective view of the head casting portion;

FIG. **22** is a cross-sectional view through line **22-22** of FIG. **9**;

FIG. **23** shows the inner cam chain cavity with the cover removed;

FIG. **24** shows a cross-sectional view through lines **24-24** of FIG. **22**;

FIG. **25** shows an underside perspective view of the valve cover;

FIGS. **26** and **27** show perspective views of the oil distribution mechanism located within the valve cover;

FIG. **28** shows a perspective of a potential mounting orientation and structure for the range extender within a vehicle;

FIG. **29** shows an enlarged view through the cam shaft drive chamber showing the oil scraper positioned between the links of the cam chain;

FIG. **30** shows a perspective view of the assembled valve cover with a portion of the outer cover member broken away to show the internal oil distribution mechanism;

FIG. **31** is a perspective view similar to that of FIG. **30** showing the entire internal oil distribution mechanism within the valve cover;

FIG. **32** shows a cross-sectional view of the engine and generator of FIG. **28**;

FIG. **33** shows an enlarged sectional view of the portion denoted in FIG. **32**;

FIG. **34** shows the crank shaft of the combustion engine in a perspective representation;

FIGS. **35**A and **35**B show the bearings on the shafts;

FIG. **36** shows a diagrammatical sketch of an engine dampening system for use with the above mentioned engine;

FIG. **37** shows a diagrammatical sketch of an alternate engine dampening system of the version shown in FIG. **36**; and

FIG. **38** shows a diagrammatical sketch of an alternate engine dampening system of the version shown in FIG. **36**.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The embodiments disclosed herein are not intended to be exhaustive or limit the disclosure to the precise forms disclosed in the following detailed description. Rather, the embodiments are chosen and described so that others skilled in the art may utilize their teachings.

Referring initially to FIG. **1**, an electrical system **10** is shown for controlling the operation of an electric vehicle. The electric vehicle may be a car, an all-terrain vehicle, a sport utility vehicle, a watercraft, or any other suitable vehicle. In the illustrated embodiment, electrical system **10** is configured for use with a car. Electrical system **10** includes a vehicle battery **36** that provides electrical power to a vehicle motor **48** for driving a drive axle **50** of the electric vehicle. A range extender **16** serves to generate electrical power for utilization in electrical system **10**, such as for charging vehicle battery **36** or for powering vehicle motor **48** of the electric vehicle. Electrical system **10** includes a vehicle control unit (VCU) **12** in communication with an electronic control unit (ECU) **14**. In the illustrated embodiment, ECU **14** is an electronic controller configured to control the operation of an engine of range extender **16**. ECU **14** illustratively provides control signals to the engine of range extender **16** via a drive-by-wire system **18**. ECU **14** may control, for example, the throttle position, the engine speed, the ignition timing, and other parameters of the engine of range extender **16**. Range extender **16** includes an electrical generator **17** coupled to and driven by the engine. See, for example, range extender **16** having generator **17** and an engine as illustrated in FIGS. **7-31** and described herein.

VCU **12** is an electronic controller configured to control the electrical systems and subsystems of the electric vehicle. For example, VCU **12** may control fan and water pump motors, control and monitor vehicle speed and vehicle motor speed, receive and execute driver inputs and commands, and control the heating and cooling system of the electric vehicle. In one embodiment, VCU **12** includes a microprocessor having software that contains instructions for controlling the startup and operation mode of range extender **16**. In the illustrated embodiment, VCU **12** is configured to apply switched voltage to ECU **14** according to the control logic illustrated in FIG. **2** to start range extender **16**. In one embodiment, ECU **14** controls the engine of range extender **16** using vehicle parameters provided by VCU **12**. Alternatively, ECU **14** may include a microprocessor having software for executing the control logic of FIG. **2** and for controlling range extender **16**.

A communication network **40** is provided for communication between VCU **12** and various components and devices of electrical system **10**. Communication network **40** illustratively uses controller area network (CAN-bus) protocol, although other suitable communication protocols between components of electrical system **10** may be used. In the illustrated embodiment, VCU **12** communicates with ECU **14**, a comfort system **20**, a driver interface **22**, a vehicle battery **36**, a rectifier **42**, an inverter **44**, a charger **52**, and a converter **54** over a communication network **40**.

Comfort system **20** illustratively includes a heating system **76** and an air conditioning system **78**. In the illustrated embodiment, VCU **12** controls the operation of heating system **76** and air conditioning system **78**. Driver interface **22** may include user inputs that allow a user to adjust the settings of the comfort system **20** of the electric vehicle.

Electrical system **10** further includes driver inputs **24** and a gear selector **26**. Driver inputs **24** illustratively include a brake input **72**, a throttle input **73**, and a mode selector **74**. Brake input **72** provides a signal to VCU **12** that causes VCU **12** to slow or stop movement of the electric vehicle by applying brakes to the wheels, for example, of the electric vehicle. In the illustrated embodiment, the electric vehicle includes a regenerative braking system that works in tandem with a mechanical brake. In particular, the mechanical brake is configured to assist with braking when the regenerative brake is unable to apply adequate braking force to meet the brake input demand. Throttle input **73** provides a signal to VCU **12** representative of the position of a throttle input device, such as a pedal, lever, or twist-grip device. In response, VCU **12** controls the speed and torque of vehicle motor **48** based on the signal provided with throttle input **73**.

Mode selector **74** provides a signal to VCU **12** representative of a selected operating mode of the electric vehicle. Exemplary operating modes include an economic mode and a sport mode. In an economic mode, the driving performance of the vehicle is limited such that the life and performance of battery **36** is maximized. For example, rapid acceleration of the vehicle may be limited in an economic mode. A sport mode provides maximum wheel performance (e.g. rapid acceleration and power) while expending the energy of vehicle battery **36** at a potentially faster rate than in the economic mode.

Gear selector **26** provides a signal to VCU **12** representative of a selected gear of operation of the electric vehicle. In the illustrated embodiment, gear selector **26** includes a forward gear, a reverse gear, and neutral. Gear selector **26** and mode selector **74** may be in the form of a switch, a button, a lever, or other suitable device configured to receive a user input for selecting the mode or gear of operation of the vehicle.

Driver interface **22** includes a mode select input **82** that provides a signal to VCU **12** representative of a selected operating mode of range extender **16**. Mode select input **82** is also configured to start and stop range extender **16**. Exemplary operating modes of range extender **16** include a battery hold mode, a range extended mode, and a battery charge mode, as illustrated in FIGS. **4-5** and described herein. In a battery hold mode, range extender **16** operates to maintain the charge of vehicle battery **36** at a substantially constant level. In particular, range extender **16** generates approximately the same or more electrical energy than the electric vehicle on average consumes during operation of the vehicle. In a battery charge mode, range extender **16** operates to increase the charge of vehicle battery **36**. In particular, range extender **16** generates substantially more electrical energy than is drawn from vehicle battery **36** on average during operation of the vehicle. In a range extended mode, range extender **16** operates to extend the range or "life" of vehicle battery **36**. In particular, range extender **16** generates less electrical energy than is drawn from vehicle battery **36** on average during operation of the vehicle. In one embodiment, driver inputs **24**, gear selector **26**, and mode select input **82** are all provided at driver interface **22**.

In the illustrated embodiment, VCU **12** controls the operation of fan motors **28** and **32** and water pump motors **30** and **34**. Fan motors **28** and **32** may be single phase or three phase motors. Fan motor **28** illustratively drives an engine fan **84** for cooling the engine of range extender **16** when the engine reaches high temperature levels. Fan motor **32** and water pump motor **30** illustratively drive a battery fan **88** and battery water pump **86**, respectively, for cooling vehicle battery **36** and related battery circuitry of electrical system **10**. Water pump motor **34** illustratively drives a water pump **90** for cooling the electrical components and circuitry of electrical system **10**, including rectifier **42**, inverter **44**, ECU **14**, VCU **12**, generator **17**, converter **54**, and vehicle motor **48**. In one embodiment, the electrical circuit of electrical system **10** is maintained at a temperature of about 60 degrees or less. In the illustrated embodiment, water pump motor **34** is further used to preheat the oil of the engine of range extender **16**.

Vehicle battery **36** is configured to provide power to vehicle motor **48** for driving the electric vehicle. Vehicle battery **36** is illustratively a 404V-280V DC battery, although other suitable voltage capacities for vehicle battery **36** may be used depending on vehicle requirements. Vehicle battery **36** is coupled to vehicle motor **48** via a voltage distributor **46**. Voltage distributor **46** is illustratively a high voltage distribution box configured to route voltage received from vehicle battery **36** and from range extender **16** to appropriate devices in electrical system **10**. In the illustrated embodiment, voltage distributor **46** is coupled to vehicle battery **36** via wires **64**, to rectifier **42** via wires **66**, to inverter **44** via wires **80**, to charger **52** via wires **68**, and to DC/DC converter **54** via wires **70**. Wires **64**, **66**, **68**, **70**, and **80** illustratively include hot and ground wire pairs capable of transferring high voltage between the respective components.

Voltage distributor **46** routes the electrical power received from vehicle battery **36** to DC/AC inverter **44**. Inverter **44** converts the DC voltage from voltage distributor **46** to AC voltage and provides the AC voltage to vehicle motor **48** via motor cables **62**. In the illustrated embodiment, vehicle motor **48** is a three-phase AC motor. In one embodiment, a regenerative braking system is utilized to generate electrical energy from the kinetic energy of the vehicle during vehicle braking. In particular, the kinetic energy of the vehicle is used to drive vehicle motor **48** in the opposite direction, thereby causing vehicle motor **48** to generate electrical energy that is fed back through voltage distributor **46**. The generated electrical energy may then be stored in vehicle battery **36** or used to preheat a catalytic converter of range extender **16**, for example. Alternatively, a separate motor may be used for the regenerative braking.

Generator **17** provides electrical power to AC/DC rectifier **42** via cables **60**. In the illustrated embodiment, generator **17** is a three-phase motor that is operated in reverse to function as an electricity generator. In particular, the engine of range extender **16** drives generator **17** and causes generator **17** to produce AC power provided to rectifier **42**. Rectifier **42** converts the AC voltage received from electrical generator **17** to DC voltage. Voltage distributor **46** routes the generated DC voltage received from rectifier **42** to the appropriate destination in electrical system **10**, such as to charge battery **36** or to drive vehicle motor **48** directly. In one embodiment, generator **17** also serves as a starter for the engine of range extender **16**. In particular, vehicle battery **36** may provide a voltage to the motor of generator **17** via cables **60**, causing the motor of generator **17** to rotate in the forward direction to start the engine of range extender **16**. As such, an additional starter motor and alternator is not required, thereby reducing the size and weight of range extender **16**.

Vehicle battery **36** illustratively includes a battery manager **38** that manages various parameters of vehicle battery **36**. In one embodiment, battery manager **38** includes a computer with software that contains limits for the discharge rate, the charge rate, the maximum and minimum voltage, and the maximum and minimum temperature of battery **36**. In particular, battery manager **38** may monitor the level of charge in vehicle battery **36** and initiate a control event detected by VCU **12** when the charge of vehicle battery **36** reaches a predetermined level. For example, when the stored charge of vehicle battery **36** reaches a predetermined low level, battery manager **38** may provide VCU **12** with a "low voltage" warning. In response, VCU **12** may instruct ECU **14** to start the range extender **16** to generate more electrical energy that is fed back into electrical system **10** for charging vehicle battery **36**. Similarly, when the stored charge of vehicle battery **36** reaches a predetermined high level, battery manager **38** may provide VCU **12** with a "high voltage" warning. In response, VCU **12** may instruct ECU **14** to stop or reduce the generation of electrical energy by generator **17**. In the illustrated embodiment, battery manager **38** is configured to communicate with various devices, including VCU **12**, on communication network **40** to assist with the management of battery **36**.

Charger **52** is configured to couple to an external power source for charging battery **36**. In one embodiment, charger **52** is a plug-in charger that connects to and draws electrical power from an electrical outlet to charge battery **36**. DC/DC converter **54** converts DC voltage from battery **36** to a lower voltage level to provide a battery source **56**. Battery source **56**, illustratively 12 volts, may be utilized by low-voltage devices of the electric vehicle, such as lights and the instrument panel.

Referring to FIG. **2**, exemplary control logic **100** is shown for controlling the operation of range extender **16**. In the illustrated embodiment, control logic **100** is contained within a memory of VCU **12**, although ECU **14** may alternatively contain at least a portion of control logic **100**.

Block **106** is true if a vehicle speed flag **102** is set or if a range extender ON flag **104** is set. In one embodiment, a button or switch located at driver interface **22** or instrument panel may be used to set range extender ON flag **104** to initiate control logic **100** of FIG. **2**. In one embodiment, the selection of an operating mode of range extender **16** with mode select input **82** (see FIG. **1**) sets range extender ON flag **104**. As such, a user may activate range extender **16** manually under certain conditions. Vehicle speed flag **102** is set when the electric vehicle is at or above a predetermined minimum vehicle speed. In the illustrated embodiment, the minimum vehicle speed required to set vehicle speed flag **102** is about 55 kilometers/hour, although other suitable minimum vehicle speeds may be selected. If the vehicle speed **102** drops below a predetermined minimum level, range extender **16** is switched OFF automatically, as described herein. In the illustrated embodiment, range extender **16** is deactivated (i.e. block **106** goes from true to false) when the vehicle speed **102** drops below about 25 kilometers/hour, although other suitable minimum vehicle speeds may be selected. With range extender **16** only operating automatically at higher vehicle speeds, the road noise or other noise from the electric vehicle serves to drown out the noise generated by range extender **16**.

The operating limits illustrated in block **110** are used to start or stop range extender **16** automatically depending on several parameters of vehicle battery **36**. The limits illustrated in block **110** are exemplary, and other suitable limits may be provided at block **110** depending on vehicle configurations. In the illustrated embodiment, range extender **16** is configured to be activated (i.e. block **110** is "true") if the voltage of vehicle battery **36** drops to 280 volts or less, the charge percentage of vehicle battery **36** is less than 80% of full capacity, and the temperature of vehicle battery **36** is less than about 41 degrees Celsius. At block **110**, if the voltage of vehicle battery **36** rises to 390 volts, if the charge percentage of vehicle battery **36** meets or exceeds 80% of full capacity, or if the temperature of vehicle battery **36** meets or exceeds about 41 degrees Celsius, the control logic proceeds to block **138**. At block **138**, action is taken by VCU **12** to respond to the exceed limitations. Depending on the cause of the exceeded limits, VCU **12** may deactivate generator **17** of range extender **16** and/or deactivate charger **52** to reduce the likelihood of overloading vehicle battery **36**.

Block **112** requires the selection of a mode of operation of the vehicle, such as the "sport" or "economic" modes described above. If blocks **106**, **110**, and **112** are all true, the control logic proceeds to block **114**. In the illustrated embodiment, range extender **16** is configured to generate a certain load (based on engine speed or rpm) depending on the vehicle speed and the selected mode of operation of range extender **16**. At blocks **114** and **122**, VCU **12** (or ECU **14**) identifies the selected mode of operation for range extender **16**. The mode of operation is illustratively selected with mode select input **82** of FIG. **1**. In the illustrated embodiment, battery hold mode, battery charge mode, or range extended mode may be identified at blocks **114** and **122**. Once the mode of operation is identified, the run flag **130** is set at block **124**.

Upon identifying the appropriate mode of operation for range extender **16** and setting run flag **130**, the control logic proceeds to block **126**. At blocks **126**, **132**, and **136**, the selected mode of operation for range extender **16** is implemented by VCU **12** and/or ECU **14**. As long as block **126** is false, range extender **16** is run according to the selected mode of operation, as represented by block **136**. As such, a startup event **140** is generated and range extender **16** is activated and run according to the selected mode of operation.

With the vehicle and range extender **16** running, the vehicle brake may be applied which causes the regenerative braking to be initiated. In such a case, both range extender **16** and the regenerative braking system generates electrical power that is fed back to vehicle battery **36**. In order to avoid a current overload of vehicle battery **36**, a flag **128** is set when the generated current supplied to vehicle battery **36** exceeds an upper threshold. For example, if the upper current threshold of vehicle battery **36** is 80 amps, flag **128** is set when the combined current generated by range extender **16** and the regenerative braking system meets or exceeds 80 amps. In this situation, range extender **16** is deactivated at block **134** by closing the throttle plate of the engine of range extender **16**, thereby by stopping the generation of electrical power by generator **17**. In one embodiment, if the upper current threshold limit is still exceeded after stopping generator **17**, the regenerative braking system is disabled or the generated current from the regenerative braking system is redirected in order to avoid overloading vehicle battery **36**. In one embodiment, flag **128** is set when the limits illustrated in block **110** are exceeded. At block **134**, a time delay may be implemented before a startup event **140** may be generated and range extender **16** may be re-activated.

In one embodiment, the mode of operation may be changed on the fly during the operation of the electric vehicle and range extender **16**. For example, a user may select a new mode of operation with mode select input **82** (see FIG. **1**) while range extender **16** is running in a different mode of operation.

If block **106** is true, the control logic also proceeds to block **146**. As represented by blocks **142**, **144**, and **146**, if the vehicle speed **102** is at or about zero and the vehicle is in a neutral gear, range extender **16** may be run to charge vehicle battery **36**. In particular, the user must manually select a button or other input device at the driver interface to set the range extender ON flag **104** and to activate range extender **16** at block **148**. The manual activation of range extender **16** at block **148** may be used, for example, when the vehicle is stopped and vehicle battery **36** is dropping to a low charge level, such as in a traffic jam.

In the illustrated embodiment, range extender **16** is configured to generate a certain load depending on the vehicle speed and the selected mode of operation of range extender **16**. In each mode of operation, the engine speed of range extender **16** varies depending on vehicle speed. FIG. **3** illustrates the engine speed and the throttle opening of range extender **16** in an exemplary battery hold mode of operation for range extender **16**. In the battery hold mode, the engine speed (RPM) of range extender **16** follows curve **116** and the throttle opening percentage of range extender **16** follows curve **118** in relation to the vehicle speed. The load generated by range extender **16** depends on the engine speed of range extender **16**. In the exemplary battery hold mode of operation, range extender **16** generates a power curve **120** (see FIGS. **4** and **5**) for the illustrated vehicle speed range.

Power curve **182** of FIGS. **4** and **5** illustrates the exemplary average electrical power needed by vehicle motor **48** to drive the vehicle on a substantially flat road or surface. As illustrated in FIG. **4**, the electrical power generated by range extender **16** in the battery hold mode is greater than or equal to the electrical power consumed on average by vehicle motor **48** when the vehicle is driving on a flat road for the illustrated range of speeds. As such, battery hold mode may be utilized when the vehicle traverses both hilly and flat terrain. In the battery hold mode illustrated in FIG. **4**, range extender **16** creates supplemental electrical energy between vehicle speeds of about 25 kilometers/hour and 80 kilometers/hour.

Exemplary power curves for the battery charge mode and range extended mode of operation are illustrated in FIG. **5**. In a range extended mode, range extender **16** generates a power curve **184** for the illustrated vehicle speed range. As illustrated, the power generated by range extender **16** in the range extended mode is less than or equal to the power consumed on average by vehicle motor **48** when the vehicle is driving on a flat surface. In the illustrated embodiment, range extended mode is configured to extend the range or "life" of vehicle battery **36** and not necessarily maintain the charge of vehicle battery **36**.

In a battery charge mode, range extender **16** generates a power curve **186** for the illustrated vehicle speed range. As illustrated, the power generated by range extender **16** in the battery charge mode is substantially more than the power consumed on average by vehicle motor **48** when the vehicle is driving on a flat surface. As such, the battery charge mode is used to charge vehicle battery **36** during operation of the vehicle.

For the battery hold and range extended modes of operation illustrated in FIG. **5**, energy generation by range extender **16** is activated when the vehicle speed reaches about 55 kilometers/hour and is deactivated when the vehicle speed drops below about 25 kilometers/hour. In the battery charge mode illustrated in FIG. **5**, range extender **16** is configured to generate electrical energy for all vehicle speeds, including vehicle speeds between 0 and 55 kilometers/hour.

With reference now to FIG. **6**, the vehicle has a cooling system shown generally at **200** having a low temperature circuit **202** and a high temperature circuit at **204**. Low temperature circuit **202** is comprised of an electrical water pump **206** and a radiator at **208** where water pump **206** circulates low temperature cooling water through rectifier **42**, inverter **44**, DC to DC converter **54**, electrical drive motor **48** and generator **17**. This cooling water also runs through an oil pre-heater located within the range extender engine as described herein.

A separate, and higher temperature circuit **204** is provided which circulates cooling water through the engine water jackets of the engine in a typical fashion. A second radiator **210** is provided for cooling the engine cooling water and a heating element **212** provides heating for the passenger compartment. The vehicle can also have an onboard electric heater (not shown) and the system can determine whether it is more efficient to run the range extender engine to provide the passenger compartment heating or to heat the engine by way of the electrical heater and recharge the batteries with the range extender.

As mentioned above, the system includes a range extender **16**, which is comprised of a generator **17** and, as shown in FIGS. **7-9**, a 4-cycle engine **290**. The engine **290** is comprised of a crankcase housing **300**, an oil pan or sump **302**, cylinder liner **304**, head assembly **306** and valve cover **308**. With reference now to FIG. **10**, plural chambers are defined in the engine and by the plural sections **300**, **302**, **304** and **306** such as engine oil sump **310**, crank chamber **312**, compression chamber **314** and cam shaft chamber **316**. With reference now to FIGS. **10**, **11** and **12**, oil sump **302** will be described in greater detail.

As best shown in FIGS. **11**A and **11**B, oil sump **302** is defined by an upper body portion **326** and a lower body portion **328** as described herein. Upper body portion **326** is comprised of side walls **330**, **332** and end walls **334**, **336**. Oil sump **302** also includes a lower floor **340** having a pedestal portion **342** and an integral tubular portion **344** extending upwardly therefrom. With reference now to FIG. **12**, a filter assembly **350** is shown installed within the oil sump **302** and includes a threaded bolt portion **352**, a tubular filter **354**, and a transition section **356**. As shown, a hole is drilled from wall **332** towards wall **330**, and partially into pedestal **342** defining apertures **360*a*** and **360*b***. The tubular portion **344** is also drilled to define a hole **362** which intersects with hole **360*b***.

As should be appreciated, hole portion **360***a* is threaded to receive bolt portion **352**. This allows filter assembly **350** to be positioned as shown in FIG. **12** with the transition portion **356** positioned in hole **360***b*.

With reference now to FIGS. **11**A, **11**B, **12** and **13**, the oil sump **302** further includes a water fed heat exchanger shown generally at **370** in FIG. **12** and described herein. With reference first to FIGS. **11**A and **11**B, the upper portion **326** of oil sump **302** includes curved wall portions **372** and **374** (FIG. **11**A) defining corresponding concavities **376** and **378** (FIG. **11**B). As shown best in FIG. **13**, water couplings **380** and **382** communicate with concavities **376** and **378**, respectively, and provide water in and out to the heat exchanger **370**. With respect now to FIG. **11**B, the lower side of oil sump portion **326** includes a plurality of U-shaped fins such as **390**, **392** which surround a center wall **398**. As shown in FIG. **11**B, a gasket **400** is positioned between portions **326**, **328** and held together by way of fasteners **402**. With respect again to FIG. **12**, two separate channels are defined, **410**, **412**, which communicate with respective water couplings **382**, **380**, as further described herein.

With reference now to FIGS. **14-17**, crank housing portion **300** will be described in greater detail. As shown, crank housing **300** is shown as a split housing defined by housing portions **300**A and **300**B. As shown, housing portion **300**B has a plurality of threaded studs **440** threadedly received in threaded apertures **442**. Housing portion **300**A includes corresponding apertures **444** positioned over the studs to complete the housing assembly. As shown in FIG. **14**, the lower housing portion **300***b* defines a crankshaft chamber **450** bound by a semi-circular wall **452** and end walls **454** and **456**. Each of the end walls **454**, **456** define bearing surfaces **458**, **460** as described herein.

The crank housing **300** also defines a plurality of mounting faces or flanges. For example, as shown in FIG. **14**, a top face **470** is defined for mating with the cylinder liner portion **304** as described herein. A generator mounting face is also defined by **472**A and **472**B, and has a plurality of mounting apertures at **474**. As shown in FIG. **15**, a lower mounting face **478** is provided for mounting with the oil sump **302**. With reference now to FIG. **16**, the two housing halves **300**A, **300**B also define a mounting face **490**A, **490**B which receive a cover as further described herein. Cam chain chamber **316**, FIG. **16**, is at least partially defined by the wall **500** on housing portion **300**B and the wall **502** on housing portion **300**A. Thus when the housing parts **300**A and **300**B are positioned together, the cam chain chamber **316** surrounds bearing surface **458** and is also bounded by a rear wall defined by surfaces **510**A on housing portion **300**A and **5108** on housing portion **300**B. As shown in either of FIG. **14** or **16**, a cam chain channel **512** is provided which communicates through the upper surface **470** of crank housing **300** and also opens into cam chain chamber **316** as best shown in FIG. **17**. As also shown in FIG. **16**, housing portion **300**B also includes a semi-cylindrical wall **514** extending forwardly from surface **5108**, having an access notch **516**, as further described herein.

As best shown in FIGS. **16** and **17**, a channel is defined adjacent to crank chamber **450** defined by channel halves **520**A (FIG. **17**) and **520**B (FIG. **16**). A port is defined by portions **522**A and **522**B (FIG. **16**) which in turn communicates with the channel defined by **520**A and **520**B. It should be understood that the inner wall **524**A (FIG. **17**) and the inner wall **524**B (FIG. **16**) define a spaced apart slot therethrough such that the crank chamber **450** communicates with the channel defined by channel portions **520**A and **520**B. Furthermore, the port defined by portions **522**A and **522**B is the only communication between the crank channel **450** and the cam channel **316**. Meanwhile the only communication between the cam shaft chamber **316** and the oil sump chamber **310** is through opening **530** (FIG. **16**) at the lowest point of this continuous wall **500**. Finally, an oil inlet is defined by apertures **536** (FIG. **17**) and **538** (FIGS. **16** and **17**). It should also be appreciated that aperture **536** is profiled to correspond with aperture **362** (FIG. **12**).

With reference now to FIGS. **18** and **19**, the crankshaft assembly is shown generally at **540**. The assembly **540** is comprised of a crankshaft **542**, which has a split shaft having halves **542**A and **542**B connected together by way of pressed pin **544**; and a connecting rod **546**. The crankshaft **542** also includes two output shaft ends, a first shaft end **550** having a coupling surface at **552** and a second shaft end **560** which is keyed to a gear set **562** having a small diameter gear **564** and a large diameter gear **566**, as further described herein. As also shown, the end of shaft **560** is bored to provide an aperture at **570** which in turn communicates with bore **572** through crankshaft portion **542**B. As shown, pin **544** includes a bore at **574** which aligns with bore **572**. Counterweights are provided at **576**.

Finally, pin **544** includes end caps **578** defining an inner pin volume at **580**, and an access opening **582** positioned between the crankshaft portions **542***a*, **542***b*. As shown, connecting rod **546** is shown positioned between the crankshaft halves **542***a*, **542***b* and rotatably mounted to pin **544** by way of a needle bearing at **590**. As best shown in FIG. **19**, the connecting rod **544** has three indents **592** on each side of the connecting rod, as further described herein. Two roller bearings **594** and **596** are positioned on opposite sides of pin **544** and rotatably mount the crankshaft assembly **542** as further described herein. Lastly, a wiper seal **598** is provided adjacent to roller bearing **596** as further described herein.

With reference now to FIG. **20**, the head assembly **306** is shown having a main body portion **600**. Assembly **306** includes double overhead cams **602**, **604** which are rotatably mounted in pairs of roller bearings **606** and **608** (only one of each pair is viewed in FIG. **20**). Cams **602** and **608** are driven by respective gears **610**, **612** and by timing chain **614**. It should be appreciated that timing chain **614** is trained around gear **564** (FIG. **19**), such that the crankshaft rotation drives the camshafts **602**, **604**. As shown best in FIG. **21**, housing **600** includes an upper wall **620** having the valve ports **622** and a lower wall **630** having apertures **632** therethrough. An access channel is provided at **634**, which is profiled to communicate with channel **512** (FIGS. **16**, **17**) and to allow the chain **614** to pass upwardly to the gears **610**, **612**.

With reference now to FIGS. **23** and **24**, other aspects of the engine will be described. As shown in FIG. **23**, a reed valve **650** is positioned over and covers port **522**. As shown in FIG. **24**, chain guides **702**, **704** are provided for guiding the chain **614** and for maintaining the proper chain tension. With reference again to FIG. **23**, a balancing gear **710** is provided in meshed engagement with gear **566**, which is driven by the crankshaft **542**. Gear **710** has a shaft **712** rotatably mounted as described herein.

As shown in FIG. **23**, a cover **740** is also shown having a flange **742** which mates with flange surfaces **490**A and **490**B of crankcase assembly **300**. Cover **740** further includes an oil distribution scraper **746**, an oil distribution channel **748**, and a roller bearing **744** which overlies shaft **712** of balance gear **710**. As shown, scraper **746** is attached to an inside surface **750** of cover **740** and includes an elongate rail **752** and a short rail **754**. An extended tongue **756** projects beyond rail **752**, **754** as further described herein.

Oil distribution channel **748** is comprised of a first seal **760** profiled for receipt over crankshaft end **560**, encompassing oil channel **570** (FIG. **22**). A second seal **762** is profiled to be positioned in aperture **538**. Finally, an oil channel is defined within cover **740** at **766** as best shown in FIG. **10**.

With reference now to FIG. **25**, valve cover **308** is shown from an underside view with oil distribution assembly **800** shown including a distribution member **802** for valve tappets/cams and rails **804**, **806** for lubricating cam shaft **602** (FIG. **20**). As shown in FIGS. **26** and **27**, distribution member **802** comprises an upper tray **810** having a perimeter wall **812** extending around the tray and around a floor **814**. A window **816** extends through the floor **814** and is profiled for residing over cam chain **614** as described herein. Mechanism **802** further includes a mounting boss **820** and openings **822** and **824** which communicate with the inner tray **814**.

With the above particulars of the engine described, the assembly of the engine will now be described. With reference first to FIGS. **11***b* and **12**, it should be understood that the oil pan **302** is assembled by placing the lower portion **328** and gasket against the lower surface of portion **326** and providing fasteners to assemble the two components, **326**, **328** together. Oil filter assembly **350** is also installed as shown in FIG. **12**.

As shown in any of FIGS. **14-17**, studs **440** are threadably received in threaded openings **442** whereupon the crankshaft assembly **540** (as shown in FIG. **18**) is positioned within crankshaft chamber **450** (FIG. **14**). This positions roller bearing **594** (FIG. **14**) on surface **460** (FIG. **14**) and roller bearing **596** (FIG. **18**) on surface **458** (FIG. **14**). This also positions seal **598** within groove **462** (FIG. **14**). It should be appreciated that this positions the gear set **562** (FIG. **18**) overlying the semi-cylindrical wall **514** as best shown in FIG. **23**. It should also be appreciated that the cam chain **614** would be laced around drive gear **564** prior to insertion in crankcase lower half **300***b*.

With the crankshaft sub-assembly positioned as described above, the upper portion **300**A of the crankcase assembly may now be slidably received by positioning apertures **444** over each of the corresponding studs **440** as best shown in FIG. **16**. As shown in FIG. **17**, upper crankcase housing **300**B is received over roller bearings **594**, **596** with pins **640** locating the bearings within receiving apertures **642** to prevent the outer race of bearings **594**, **596** from spinning during the rotation of the crankshaft. It should also be appreciated that during the assembly of the upper crankcase housing portion, the cam shaft drive chain **614** is fed upwardly through aperture **512** (FIG. **17**) to pull the chain upwardly through the crankcase.

With respect now to FIG. **10**, with a piston **636** attached to connecting rod **544**, cylinder liner **304** may now be placed over piston **636** and downwardly to be received on the top surface **470** (FIG. **16**) of the upper crankcase housing **300**A. While not specifically described, it should be appreciated that cylinder liner **304** has apertures which match with studs **440** such that cylinder liner stacks on top of crankcase housing **300***a*, as best shown in FIG. **10**.

With the head assembly **306** as shown in FIG. **20**, head assembly **306** is positioned over studs **440** with holes **632** (FIG. **21**) received therein. It should be appreciated that studs **440** have a length appropriate to be received through apertures **632** with enough clearance to receive fastening assemblies such as washers and fastening nuts. The cam chain **614** is then assembled around associated cam drive gears **610**, **612** to the position shown in FIG. **20**. Valve cover **308** may then be attached over head assembly **306** by way of fasteners.

With reference now to FIG. **28**, the range extender assembly **16** is shown mounted within a vehicle forward of the drive motor **48**. The range extender engine **290** is attached to generator **17** where generator **17** is mounted along, and facing forward relative to, longitudinal axis L. Drive motor **48** has output drive couplings **800** arranged along a transverse drive axis D. As shown, a frame bracket **802** is provided having mounting cylinders **804** which include rubber grommets to mount the range extender assembly **16** at three positions.

As mentioned above, the range extender **16** only operates for the purpose of charging the system batteries and therefore is not constantly running. For that purpose, the oil is preheated by way of system water flowing through couplings **380**, **382**. This flow of water is constant during the operation of the vehicle in order to maintain the oil at a proper operating temperature. For that same reason, the catalytic converter of the range extender is also preheated for a run ready condition.

The engine is designed such that oil pressure to the bearing points is not necessary but rather a small flow of droplets are only required for proper lubrication. As mentioned above, all of the bearings are roller bearings, particularly the main crank bearings **594**, **596**; and the connecting rod bearing is a needle bearing **590** (FIG. **18**). As also mentioned, the overhead cam bearings **607**, **608** (FIG. **20**) are also roller bearings. Thus a small amount of oil flow is adequate for the roller and needle bearings lubrication.

As described, engine **290** does not even have a traditional oil pump but rather, the oil is siphoned under the natural operational movement of the piston. With reference to FIGS. **10**, **18** and **19**, the engine lubrication will be described. It should be appreciated that in FIG. **10**, piston **636** is shown in the top dead center (TDC) position. During the power stroke, piston **636** is forced downwardly and the reduction of volume in crank chamber **312** (together with the blow by gases around the piston) pressurizes crankcase chamber **312**. Recall that only one port communicates between the crankcase **312** and the cam chain drive chamber **316**, that is through port **522**. Thus during the compression stroke, the gases in crankcase **312** exhausts through reed valve **650** (FIG. **23**).

When the piston is at its lowest position, or bottom dead center (BDC), the piston begins to move upward, beginning the compression stroke compressing air and fuel within the compression chamber **314**. The vacuum created within chamber **312** draws oil from the oil sump chamber **310** through filter **354** into passageway **362**, **536**, **766** and into passageway **570** within the crankshaft **542**. This also draws oil into the internal volume **580** within pin **544** through passageway **572**. Oil reaches the needle bearings **590** through aperture **582**. The continued rotation of crankshaft **542** causes the centrifugal force on the oil to be released from the needle bearing **590** through passage ways **592** (FIG. **19**) into crank chamber **312**. In fact, once the engine is running, the centrifugal force of the oil together with the surface tension of the oil fluid, helps draw the oil through the aforementioned passages. It should also be appreciated that during the power stroke, the oil that is in the crank chamber **312** is exhausted through the reed valve **650** into chamber **316**.

With reference again to FIG. **23**, the oil level is shown at its natural level within chamber **316**, and aperture **516** allows oil to seek a level within semi-circular wall **514**. Rotation of the gears **566**, **710** (FIG. **23**) causes oil to be thrown onto rail **752** and to pool with the help of rail **754** and traverse down rail **756**. The oil is thereafter picked up by chain **614** and carried through the crank housing **300**, liner **304**, and into the head **306**.

With reference now to FIGS. **30** and **31**, the lubrication within the head assembly **306** will be described. As shown first in FIG. **30**, chain **614** throws oil into member **802** through window **816** and collects within member **802**. Oil then drips through aperture **822** (FIGS. **26-27**) and through opening **824** (FIG. **27**) to lubricate lobes **605** on cam shaft **604**. The rotation of the chain **614** together with the cam **602**, **604**, causes a spewing of the oil against rails **804**, **806** (see FIG. **25**) which causes droplets of oil to lubricate the lobes **603** of cam **602** (FIG. **20**). Also, due to the inclination of the engine (see FIG. **7**) that is, with oil distribution member **802** on the high side, oil is also distributed to lobes **603** of cam **602** (FIG. **20**). The general spray of oil within valve cover **308** lubricates bearings **606**, **608**. Oil is returned to the cam chain chamber **316** through the chain access openings **512** (FIG. **16**) and **634** (FIG. **20**) and back to oil sump chamber **310** by way of aperture **530**, which continues the lubrication cycle.

With reference now to FIG. **32**, a sectional view of the range extender with coupled single-cylinder engine **290**, the generator **17** located on the left and the engine block of the combustion engine, here a single-cylinder engine, on the right. The generator **17** is located in a generator housing **900**.

Of the combustion engine can be seen the crank shaft **542**, the crank pin **544**, the connecting rod **546**, the piston **636** as well as the cylinder liner **304** and of the electric drive can be seen the likewise hollow rotor shaft **902** of the generator with the generator/rotor **904**.

As can be seen from FIG. **33**, the crank shaft **542** and the rotor shaft **902** are connected by a self-centering connection screw **906**, whereby on the crank shaft, a stub shaft **550** with spur gearing **552** and on the rotor shaft **902** a corresponding shaft **908** with spur gearing **910** are arranged, whereas this serration is self-centering, and is known as a "Hirth-Serration". The two shafts are connected by a connecting screw **912** and the two housings **900** and **304** are connected by screws **914** without centering because the Hirth-Serration does the centering.

An advantageous consequence of such a connection is a substantial simplification of the bearings of the two shafts, which enables simple length adjustment of the shafts due to temperature changes. This construction only requires a fixed bearing **920** in the form of a ball bearing for the rotor shaft **902** and a first floating bearing **922** as ball bearing or roller bearing in the generator housing or inner ring as well as third and fourth floating bearings **594** and **596** as roller bearings without axial in-runs in the engine housing, whereas the inner ring is pressed on the crank shaft or the crank shaft directly serves as running surface for the floating bearing without inner ring. The floating bearings **594** and **596** can also be constructed as ball bearings with a slide fit in the housing or on the shaft.

From the above described arrangement of the coupling, numerous advantages result, such as simple assembly by only one screw through the hollow shaft of the generator; simple preassembly of the two components combustion engine and generator; the connection is configured such that the prestress force of the screw is in every situation bigger than the torque and bending moments generated by the combustion engine which work on the serration, thus achieving a very rigid connection and enabling use of the high rotary mass of the generator as engine flywheel mass.

As the serration is self-centering, additional centerings on the housing are omitted. In this manner, an over-determinacy in the assembly can be avoided and the concentricity as well as the alignment of the two aggregates is always achieved. In the axial direction, minor tolerances are possible.

The shaft connections are made first and subsequently the housings are screwed together. Due to the high precision of the Hirth-Serration in the axial direction, it is possible to fix the whole connected shaft with only one axial bearing, by which the known problems with respect to linear expansion due to temperature influence can be eliminated.

As the generator is very sensitive to the play both in radial and axial directions because of the efficiency of the windings and the permanent magnets, and as the efficiency drastically deteriorates with large play, it would be ideal if the generator could be aligned exactly and all of the linear expansion on the combustion engine could be absorbed and balanced in spite of the rigid connection. The axial alignment on the generator is important because the rotation speed and position measurement of the generator is read by a decoder/rotary encoder mounted on the end side. This decoder is not able to overcome long axial distances because of its design. The axial alignment of the generator housing and the generator shaft is thus preferably to be made on the side of the decoder.

For this reason, the combustion engine can be configured such that it can absorb all of the length extension of the connected shaft in the crankshaft drive. Crank shaft and connection rod have enough play in axial direction to absorb the extension. The axial bearing on the engine can be omitted. The crank shaft and the connection rod merely have an in-run for limitation in axial direction, which is only used in the pre-assembly state of the engine without the generator.

As soon as the engine and the generator are connected, the generator takes over the axial alignment. The bearings on the engine may be fabricated with ball bearings as floating bearings as set out in FIG. **35** or alternatively with roller bearings or spherical roller bearings. The connection rod has enough play on the piston pin to absorb the axial extension. Below, the connection rod passes between the crank webs. This leads to a compact combination of the aggregates, whereby the generator with its large rotary mass is used as flywheel on the combustion engine, thus resulting in a substantial weight saving and an optimization of installation space.

With reference now to FIG. **36**, an engine dampening system **950** for engine **290** and generator **17** is shown. Engine **290** includes an air intake system **952** comprised of an air filter **954** coupled to throttle body **956** and to air manifold **958** by way of hoses **960**, **962**. As shown, air filter **954** is attached to frame **964** by way of a coupling mechanism shown generally at **966**. Coupling mechanism **966** could be a direct connection onto the frame or could be a bracket of known construction. Without dampening system **950**, engine **290** may vibrate causing vibration transfer to the air filter **954** and to frame **964** which may be felt by the driver and/or passengers. This vibration is enhanced by the remote location of the throttle body **956** which is coupled directly to engine **290**.

As shown vibration dampening system **950** is comprised of a plurality of support arms **970** rigidly connected to engine **290** and also coupled to a dampening weight **972**. Dampening weight **972** may be connected only engine **290** as shown in FIG. **36**, or may be directly and rigidly coupled to throttle body **956** by way of coupling **974**, as shown in FIG. **37**.

A further alternative as shown in FIG. **38**, allows dampening weight **972** to be movable relative to throttle body **956** by way of coil springs **976**, **978**. In this example, rod **974'** passes through mass **972**, with springs on opposite sides of mass **972**. For a single cylinder engine as shown herein, it has been found that a mass of approximately 6 KG is appropriate.

Thus as shown, vibration from engine **290** is transferred to dampening weight **972**. In the embodiment of FIG. **36**, the engine vibration alone is dampened, and in the embodiment of FIGS. **37** and **38**, throttle body **956**, due to its direct coupling to dampening weight **972** through coupler **974** is also dampened, and vibrates at the same frequency as weight **972** and engine **290**. In all embodiments, less vibration is inherently transferred to frame **964**.

The invention claimed is:

1. A serial hybrid electric vehicle with coupled combustion engine which serves to extend the operating range, comprising: a crankshaft of the engine being fixedly connected to a shaft of a generator, the generator including a rotor, wherein a fixed bearing and a first floating bearing are located on opposing sides of the rotor of the generator and a plurality of bearings on a side of the engine are configured as floating bearings in order to absorb length extensions of the shafts caused by temperature influence.

2. The electric vehicle according to claim **1**, wherein the fixed bearing is an outboard bearing of the generator, acting as a thrust bearing for the crankshaft and generator shaft.

3. The electric vehicle according to claim **1**, wherein the floating bearings on the generator and on the engine are constructed as roller bearings with an inner ring.

4. The electric vehicle according to claim **1**, wherein the generator acts as a flywheel for the combustion engine.

5. The electric vehicle according to claim **1**, wherein the crank shaft of the combustion engine is coupled to the generator of the range extender by a self-centering spur gearing.

6. The electric vehicle according to claim **1**, wherein the two shafts are hollow and connected by a connecting screw.

7. A serial hybrid electric vehicle with coupled combustion engine which serves to extend the operating range, comprising:

a crankshaft of the engine being fixedly connected to a shaft of a generator,

wherein a fixed bearing and a first floating bearing are located on a side of the generator and a plurality of bearings on a side of the engine are configured as floating bearings in order to absorb length extensions of the shafts caused by temperature influence, and

wherein the crank shaft of the combustion engine is coupled to the generator of the range extender by a self-centering spur gearing.

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